Animal procurement in the Late Neolithic of the Yangtze River Basin:

Integrating the fish remains into a case-study from Tianluoshan

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DECLARATION

I, Ying Zhang, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

ABSTRACT

This thesis aims to investigate the subsistence economy in the late Neolithic Lower Yangtze River region, by studying the faunal remains from Tianluoshan (4,900-4,000 Cal BC), and integrating with the other environmental data. Considering that the excavation at Tianluoshan is still proceeding, this research only includes the animal remains which were collected until the year of 2010.

There are mainly two categories of animal remains in the Tianluoshan assemblage, fish and mammals, which are analysed separately due to the differences in retrieval strategies and research methodologies. The study of fish remains is emphasised, as it is a new area in the archaeological research about this area, and may contribute to broadening our understandings about subsistence. Standard zooarchaeological methods and approaches are applied in the study of both remains. The methods of body length reconstruction and seasonality assessment using skeletal parts are used to study three predominant fish in the assemblage, snakehead (*Channa argus*), crucian carp (*Carassius auratus*) and common carp (*Capio capio*), to infer the fishing strategies and scheduling. In addition, an extra step of building up a fish reference collection was necessary for this research.

Three major mammalian species are studied in detail, which are sika deer, muntjac and pig. Cull patterns, body part representation and body dimensions are used to analyse them, however, for different purposes. As the most intensively captured cervids at Tianluoshan, sika deer and muntjac are used to interpret the hunting activities. On the other hand, the analysis of pig remains at Tianluoshan aims to identify its domestication status, since the process of pig domestication in the Lower Yangtze River region is still under debate.

Finally, I will attempt to place the food resources back in the ecosystem, in order to interpret the subsistence economy with each element placed in a broader background, e.g. the interaction and inter-relationship between the use of mammals, fish, plants and environment. This study will contribute to understanding the subsistence economy of the middle Neolithic Age in the Lower Yangtze River region, especially regarding the use of aquatic resources and the development of pig domestication.

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Chapter 1 Introduction

This thesis investigates the subsistence economy of the late Neolithic in the lower Yangtze River region, by studying the animal remains from Tianluoshan (4,900 – 4,000 Cal BC), a well-preserved Hemudu culture site. As excavation is still proceeding at Tianluoshan, this research only includes fish and mammal remains collected before 2010.

The Hemudu culture represents the late Neolithic phase of the 5-phase system in the lower Yangtze River region. It has been well-known as an agricultural society with large amount of rice remains and domesticated animals uncovered since the 1970s (Chang, 1986, Bellwood, 2007, 2005). In the study of Chinese Neolithic archaeology and agriculture development, Hemudu has always been a key site. The discovery of Tianluoshan provides a second opportunity to study the subsistence of the Hemudu period in detail.

A pilot study of the mammalian remains collected in 2004 was undertaken in 2009, attempting to address the subsistence economy. The results are presented in my master degree thesis. That study, however, raised more questions than it solved. Why did the pig remains show so many features of wild boar while the Hemudu culture had been defined as an agricultural society? What were the deer hunting strategies and what did they imply? Why did the Tianluoshan and Hemudu people choose to hunt and eat so many skinny monkeys? The biggest question marks were for the numerous fish vertebrae. What species were they? Were they freshwater fish or marine fish? Although I did not know how to identify a vertebra at that time, I was

sure most of them did not look like the cyprinids that Nakajima and colleagues had identified in their pioneering study of the fish bone pit from the site. Plus, how did people catch so many fish with so few fishing tools? A few archaeologists had started to reconsider the plant subsistence of the Hemudu culture. Clearly, the animal subsistence required a thorough study as well.

Research questions

In general, this thesis aims to interpret the subsistence economy of the Hemudu culture through the systematic study of faunal remains from Tianluoshan. This subject is further broken down into the following questions:

Firstly, what do the fish remains indicate about the subsistence economy at Tianluoshan? This question will be answered by solving these issues sequentially: 1) what fish species are presented at Tianluoshan? 2) when and where did fishing take place? and 3) what were the fishing strategies and fishing techniques?

In order to interpret the mammal subsistence, the following questions are asked. Firstly, what was the status of pig; were they domesticated or wild? There is a need to reconsider existing opinion of the domestication process in the lower Yangtze River region on the basis of my Master's pilot study of Tianluoshan fauna. Secondly, the hunting strategies will be discussed based on the analysis of three major food mammals, including cull patterns and seasonality. Finally, the results will be integrated to consider subsistence practices as a whole.

Since the methodological approaches for mammals, fish, and plant remains differ from each other, the research of these remains is normally carried out independently. Therefore, an extra step is required to integrate the

zooarchaeological and archaeobotanical research to generate a broad view of the subsistence economy. Resource exploitation in wetland environments will be a special focus of this research.

Approaches

The following methods and approaches are adopted in this thesis.

First, standard zooarchaeological approaches are applied to study the animal remains from Tianluoshan, including body part representation, metrical analysis, and age assessment. These methods are used to define the status of pig, and to discuss the hunting strategies at Tianluoshan. Plus, the LSI (Logarithm Size Index) technique is employed to investigate morphometric variability in pig size through time.

Second, the standard methods for studying fish remains, including making reference collections, identification, body length reconstruction, and seasonality analysis, are applied to investigate the fishing strategies at Tianluoshan. Limited by materials, only vertebrae, basioccipitals, and pharyngeal teeth are analysed in detail using these methods.

The discussion of fishing methods and techniques at Tianluoshan is mostly based on the biological and ethnographic record due to a lack of direct archaeological evidence. Fish capture methods of the world are reviewed, and the ones adaptive to wetland fishing are selected for further consideration. Since there is barely any literature recorded for wetland fishing, ethnographic records of fishing in rice fields, which are essentially artificial wetlands, are referenced. These records provide lines of evidence to help answer the puzzle of the archaeological record at Tianluoshan,

where there massive fish bone deposits but very few fishing tools.

Fourth, Taxonomic Habitat Index (THI) is introduced to examine the ecological diversity of mammalian remains, and then modified by integrating with the MNI values to evaluate the intensity of resource exploitation in various environment types. The THI method is applied to analyse the mammal, fish, and plant remains. It bridges the zooarchaeological and archaeobotanical by transferring the resource exploitation into the same index level.

Framework of the thesis

The thesis is divided into nine chapters.

Chapter 2 reviews the environmental and cultural background of the study area. Previous research on the climatic and environmental change and the fluctuation of sea levels has been summarized. The staging theories of the cultural sequence in the lower Yangtze River region are reviewed in the following section of this chapter, and the 5-stages system proposed by Yan and colleagues is adopted when defining the archaeological cultures in this thesis. In this chapter, our current knowledge about the Hemudu culture is emphasized, providing background information for the discussion of subsistence economy at Tianluoshan. In addition, research about the different aspects of Tianluoshan is outlined.

The study of fish remains in archaeology is a new domain for Chinese archaeology. Chapter 3 reviews the research questions and approaches which are essential for studying fish remains before proceeding to the fish analysis in the subsequent chapters.

The approaches and procedures for studying animal remains are presented in Chapter 4, fish and mammalian remains separately. The methods used for fish remains analysis included body size reconstruction and seasonality estimation. For mammals, the methods for ageing different animals are introduced respectively.

The results of analysis are given in Chapters 5, 6, and 7, and integrated in Chapter 8. Chapter 5 presents the results of the analysis of the fish remains. The range and relative proportions of fish species from stratigraphic layers and the 'fish pit' is presented respectively. The taphonomic issues, which might have influenced the presence and the preservation conditions of different fish remains, are considered in the analysis. The body lengths of the three most important fish are reconstructed, and the fishing seasons for these fish are also investigated in this section, in order to understand the fishing strategies employed at Tianluoshan.

Chapter 6 discusses the likely fishing strategies, including the fishing grounds, selection of species, fishing tools, and fishing seasons. Various lines of evidence are used in this discussion, such as the biological attributes of fish, environment factors, a review of global fish capture methods, archaeological evidence, and ethnographic records.

The primary data and discussion of the mammalian remains are presented in Chapter 7. The range and relative proportions of the Tianluoshan assemblage is presented in the first part of this chapter. Subsequently, the animal remains are analysed by species, and three major food animals are emphasized, these being sika deer, pig, and mutjac. The pig remains are analysed in details, in order to attempt to define the status of *Sus* in the Hemudu culture. Data from the sequential sites in the lower Yangtze are used for comparison, in order to discuss the process of pig

domestication in this area. Sika deer and muntjacs are analysed to investigate their hunting strategies at Tianluoshan, including the selection of age, sex, and seasonality of deer hunting.

Chapter 8 summarizes the hunting-fishing-gathering mode of Tianluoshan from various aspects, drawing together the results of faunal analysis from the previous chapter. The archaeobotanical dataset is integrated with zooarchaeological study for a broader view. In the discussion, the subsistence economy is interpreted as a complex ecosystem the elements in which are related. The following elements are highlighted: the rice-fish eco-subsistence, the hunting and fishing strategies, scheduling the exploitation of various resources throughout a year, and the spatial dimensions of these subsistence practices. Finally, the discussion is put in a broader context of Neolithic China to gain an understanding of the evolution of subsistence in the lower Yangtze River basin and the different development patterns between the Yangtze and the Yellow River region.

Chapter 9 states the conclusion and future research plans.

Original contributions

This thesis provides the first case study of Neolithic fish remains from the lower Yangtze River region. It provides an interpretation of a subsistence system in which fish are heavily incorporated, and answers the questions raised at the very beginning of the research. For the purpose of identification, I have established an important fish bone reference collection, containing several common freshwater fish from China. It also contains skeletal material from a group of snakeheads which were specifically collected for analysing fishing seasons. Methodologically, this research

suggests that fish vertebrae are important research materials for investigating the role of fish in subsistence.

For the mammalian remains, the status of pig is determined through careful analysis from various perspectives. An overview of the data from the sequential Neolithic sites suggests a delayed pig domestication pattern which differs from the current opinion. However, this conclusion tallies with the subsistence pattern from recent archaeobotanical research, and contributes to the study of animal subsistence. The mammal remains are thoroughly analysed to investigate the hunting strategies at Tianluoshan, including the cull patterns, scheduling, and the spatial dimensions of hunting practice. This thesis provides a comparable example for similar studies in the lower Yangtze.

Finally, this thesis attempts to integrate zooarchaeological research with archaeobotanical studies, and therefore to interpret the subsistence economy more completely. The temporal and spatial dimensions of exploiting the animals and plant resources are brought together, indicating these aspects are interrelated in the subsistence system. Integrated research in this region may improve our knowledge about the subsistence in the future.

Chapter 2 Background review to the study area

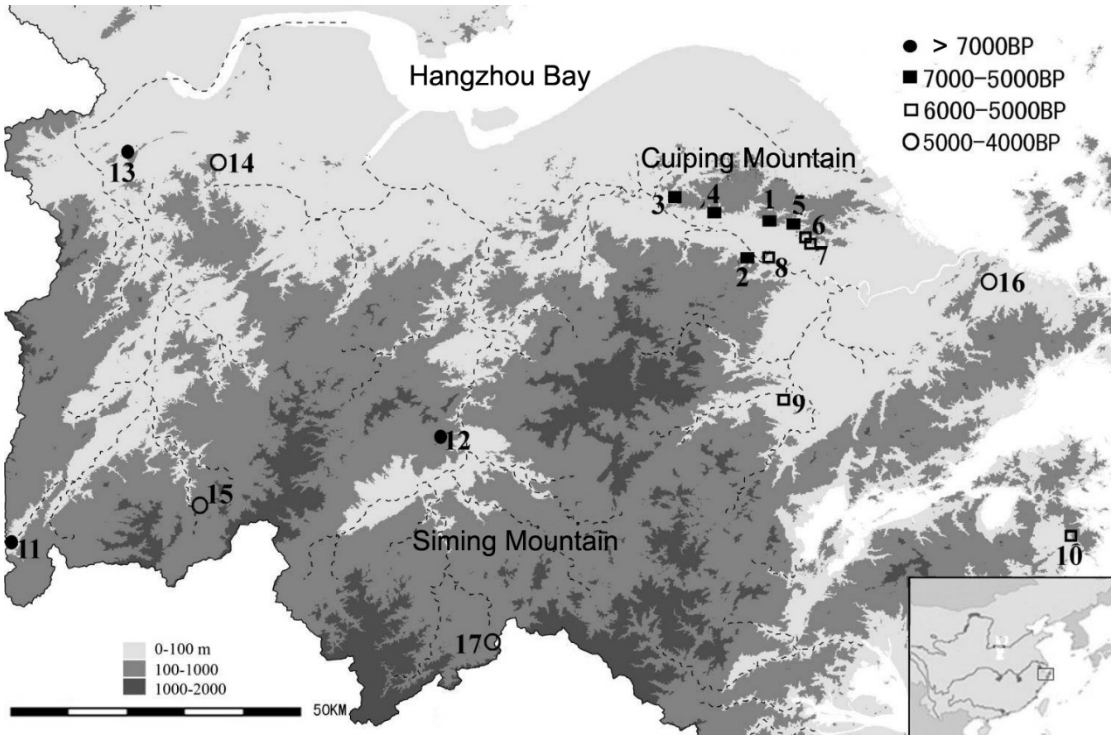
The subsistence economy can be easily influenced by many factors, such as natural environment and cultural reasons. This chapter presents the physiographic, palaeo-environmental, and cultural conditions of the study area, aiming to provide an overall background for the study of animal remains and subsistence economy at Tianluoshan.

There will be four parts to the background information in this chapter. The review starts with an introduction of the natural settings, such as the physiographic conditions, environment, climate, and vegetation in the study area. Holocene climatic and environmental change is presented in part two, focusing on the period when Tianluoshan was occupied. Section three presents the cultural background in the lower Yangtze River region. The archaeological cultural sequence is reviewed, in order to give a profile of the cultural development of the study area. In this section, the unique material culture of the Hemudu Culture shall be presented in detail, followed by an overall introduction of the site of Tianluoshan. The last section summarizes the current understanding about the subsistence economy of the Hemudu Culture, drawn from evidence from both plant and animal remains. Great progress has been made in this field, especially on the topic of rice cultivation and domestication.

2.1 Physiographic and environmental settings of the study area

Normally, China can be geographically divided into northern and southern parts

by the demarcation line of the Qinling Mountain and the Huai River. It is also the division line for different types of vegetation. The geographic division has played a very important part in the prehistory and history of China, and it is still a major influence in modern China. The Yellow River in northern China and Yangtze River in Southern China are considered as the cradles of agriculture and civilization. Plenty of archaeological sites have been discovered along these rivers and their tributaries.



1 - Tianluoshan; 2 – Hemudu; 3 – Tongjiaao; 4 – Zishan; 5 – Fujiashan; 6 – Cihu; 7 – Xiaodongmen; 8 – Xiangjiashan; 9 – Mingshanhou; 10 – Tashan; 11 – Shangshan; 12 – Xiaohuangshan; 13 – Kuahuqiao; 14 – Siqianshan; 15 – Jianshanwan; 16 – Shaxi; 17 – Xiachang.

Figure 2.1 The landforms of the Ningbo-Shaoxing Plain area and the distribution of early to middle Neolithic sites (Qin et al., 2010)

The site of Tianluoshan (30°01'N, 121°22'E) in Yuyao County, Zhejiang Province, is located in the lower Yangtze River region, which is formed by a group of low-laying plains with a dense hydrology network. The plains to the south bank are separated by hills. Tianluoshan lies in the east of Ningbo-Shaoxing Plain, which extends to a width of 150 km to the south side of Hangzhou Bay. Although it belongs to the grand

lower Yangtze River region, there is quite a distance from the site to the Yangtze River. The rivers on the Ningbo-Shaoxing Plain drain directly into the East Sea rather than the Yangtze River.

At closer range, Tianluoshan is located in a small valley on the Ningbo-Shaoxing Plain which is formed by the Cuiping Hills and Siming Mountain on the south boundary of the Plain (Figure 2.1). The main stream on the plain, Yao River, passes through the valley, and Tianluoshan and Hemudu lay on different sides of the river. It is the lower part of the plain, with an altitude of about 2.3 m above sea level. Geological investigation indicates that the physiographic settings in this area have remained the same since Jurassic and Cretaceous periods (Zhejiang Provincial Bureau of Geology and Mine, 1989).

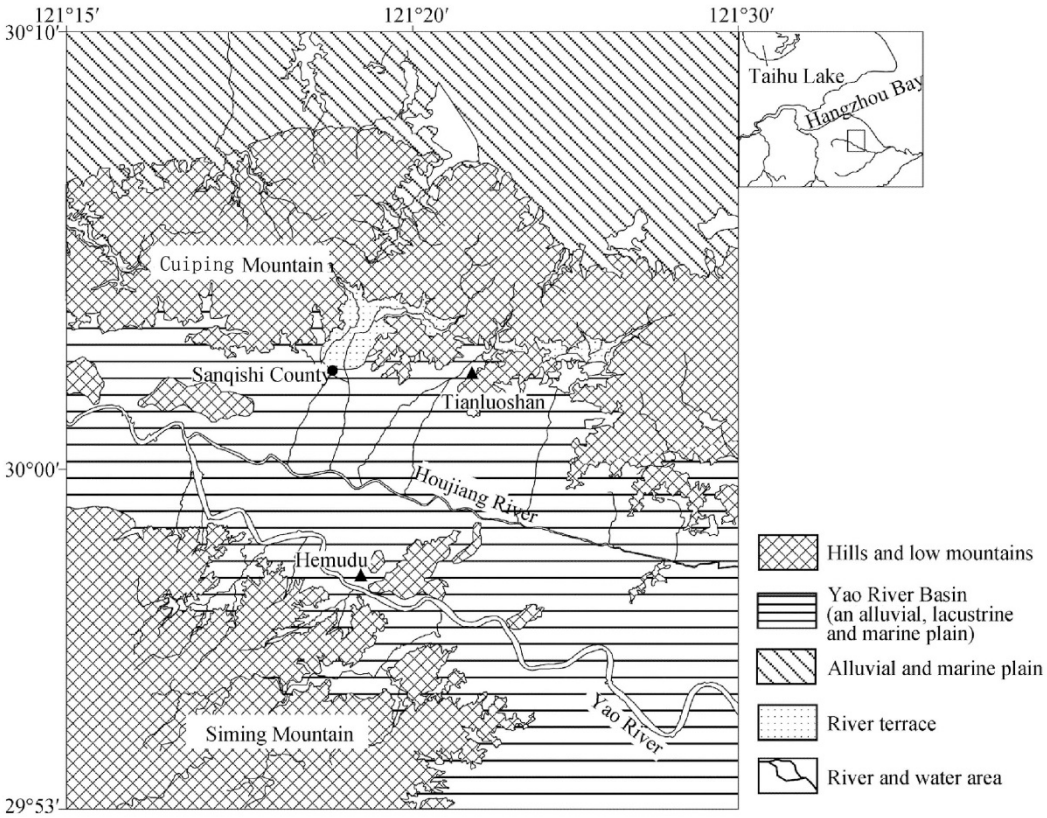


Figure 2.2 Geomorphological map of the area around Tianluoshan (Li *et al*, 2010)

Located in the subtropical zone, the lower Yangtze River experiences a subtropical monsoon-dominating climate, characterized by a mild and humid climate (mean temperature 16.2℃), rich precipitation (about 1,300 – 1,400 mm per year) and plenty of sunshine (2,061 hours annually). The weather shifts significantly between seasons. The winter months are slightly cold and dry due to the cool current from Siberian Plain, with a mean temperature of 3℃ - 4℃. Summer is hot and humid, but with little precipitation because of the interaction of the southeast monsoon and subtropical anticyclone. Most of the rainfall occurs in spring (March to June) and early autumn (August to September), and the second rainy season is highly related to the attack of hurricanes (Chen, 1985, P93-121). Climatic research has also pointed out that this subtropical monsoon climate is not influenced much by the low-lying physiographic setting in east China.

The warm climate, rich precipitation and sunshine make the lower Yangtze River region an ideal place for vegetation growth, animal habitats, and human occupation. The natural vegetation in this area is a northern subtropical mixed broad-leaved evergreen / deciduous broad-leaved forest with diverse species. The characteristic taxa include deciduous broad-leaved trees such as *Quercus* (oak), *Liquidambar* (sweetgum), *Platycarya* (dyetree), *Dalbergia* (rosewood), and broad-leaved evergreen species such as *Cyclobalanopsis* (evergreen chinquapin)*, Castanopsis* (chinquapin), *Elaeagnus* (oleaster), *Ligustrum* (privet), *Ilex* (holly), and shrubs like *Euryale* (foxnut), and *Ternstroemia* (Wu, 1980, Duan, 1989, Chen, 1985). The animals in this region today are mainly the widely distributed ones, such as *Typhlomys cinereus* (dormouse), *Lepus sinensis* (hare), *Pipistrellus io* (bat), *Hydropotes inermis* (water deer), *Elaphodus cephalophus* (tufted-hair deer), and *Muntiacus crinifrons*

(black fronted muntjac). Some species that inhabit southern China (i.e. Guangdong province) are also found in this area, such as *Cervus unicolor* (sambar), *Macaca speciosa* (stump-tailed macaque), *Macaca mulatta* (rhesus monkey), *Paguma larvata intrudens* (masked palm civet) and *Rhizomys sinensis* (bamboo rat) (Zhang, 1978).

The lower Yangtze River region has a long agricultural tradition of rice, and it has grown into one of the richest farmlands across the country beginning more than 1,000 years ago. The advantageous climatic conditions possibly contribute most in this procedure. Animal domestication is also considered to have started early. Thanks to the rich natural resources and the subsequent well-developed agriculture, complex civilization was able to be sustained on this land, such as the Liangzhu Culture. The Hemudu period is considered to be the starting point of these civilizations in the region.

2.2 The Holocene climate and environment in the lower Yangtze River region

Studies on the palaeo-environment and Holocene climate in the lower Yangtze River region have roughly built up the sequence of environmental and climatic change in the past 10,000 years. In general, the Early Holocene and Middle Holocene were warmer and wetter in eastern China than the present condition, and southern vegetation zones had shifted northward (Yu et al., 1998, 2000).

The reconstruction of palaeovegetation and palaeoclimate is generally based on the radiocarbon-aged pollen-spore record from drill cores and archaeological sites. Yi *et al* (2003) have divided the period from late Pleistocene to Holocene (11,000 - 1,100 years BC) into eight phases according to a high-resolution pollen record from two boreholes at the Yangtze River delta. The cool/dry and warm/wet phases

appeared alternatively from late Pleistocene. Among all the phases the one paralleled with the Hemudu culture period is the mid-Holocene “hypsithermal” (5,600 – 2,800 cal yr BC), represented by a large expansion of subtropical evergreen-deciduous broad-leaved forest. The mean temperature during this climatic optimum could be 2 - 4℃ warmer than that of today. Zhang (2006) also established a sequence of pollen-spore assemblages, inferring that the climate around 6,000 to 4,500 years BC was about 2℃ warmer and wetter. The same climate possibly lasted until one or two thousand years later, as there is a big gap (about 3,000 years) between this dated age and the one of the next phase; but the researcher did not mention it in this paper. Liu *et al* (2007a) have recorded similar results at the estuary of the Qiantang River (Hangzhou Bay). Geochemical analysis suggests that the climate was warm and humid from 5,000 to 4,000 years BC, and it had turned cool and dry since then (Tao et al., 2006).

The Mid-Holocene vegetation has attracted much attention from scholars. For example, the International Geosphere-Biosphere Programme (IGBP) has set up a sub-project BIOME6000 to produce an adequately documented data-set of reconstructed biomes for the period 4,000 years BC. The study of reconstructing biomes in mid-Holocene China involved the biomization method, which has been successfully tested in Europe, Africa and North America (Prentice and Webb III, 1998). The results show significant variation of biome distributions comparing the mid-Holocene with the present. In eastern China, evergreen forests extended 300 km northwards, about 3 latitude degrees (Yu et al., 1998), implying a warmer winter and a correspondingly weakened winter monsoon (Shi et al., 1992).

Although the chronological division in each of the research studies described

above is slightly different, the different strands of research all come to a similar conclusion: in the period 5,000 to 4,000 years BC, i.e. when the Tianluoshan site was occupied during the Hemudu Culture Period, the climate was warmer and wetter than that of today. It is quite similar to the climate in southern China today, such as Fujian and province. From late Hemudu culture period, the climate tended to be temperate and mildly dry. Some authors suggest that this climate change may have accelerated the decline of the Hemudu culture (Li et al., 2009, Mo et al., 2011).

In palaeo-environment studies, the vegetation and climate are reconstructed through micro plant remains such as pollens and phytoliths. However, the plant types from archaeological sites usually differ from the functional plants (PFTs) in biome reconstruction. Considering this factor, Qin *et al* (2010) map the distribution of Neolithic vegetation using macro plant remains such as seeds and fruits, and hence discuss the exploitation of different catchments around the site. The advantage of this mapping is that it can illustrate the distribution in a small scale area in detail.

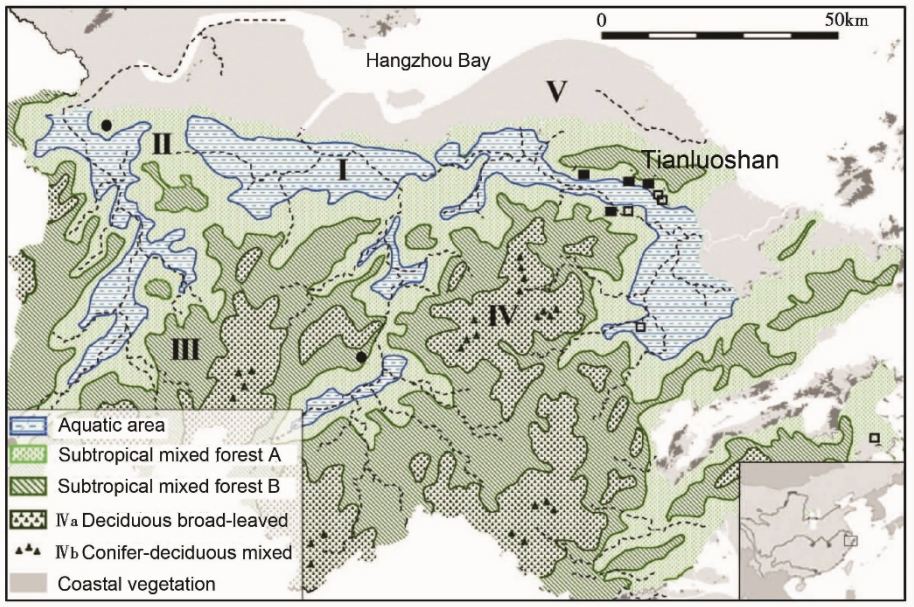


Figure 2.3 The vegetation reconstruction of Hemudu Culture period in the south of Hangzhou Bay area, including Ningbo-Shaoxing Plain (Qin et al., 2010).

In the plains area, there were plants which adapt to humid and aquatic environments, including *Salix*, *Trapa* (water chestnut), *Euryale* (foxnut), *Nymphoides*, *Oryza* (rice), *Typha* etc. In the subtropical evergreen and broad-leaved forest (Figure 2.3, mixed forest A) at the foot of hills, there were *Albizia*, *Broussonetia*, *Ficus*, *Armeniaca*, *Vitis*; *Camellia* and *Zelkova* could be found in valley foothills. At the elevations between 100m to 800m, there was also mixed forest of evergreen and broad-leaved trees (Figure 2.3, mixed forest B), but dominated with different trees, including *Lithocarpus*, *Cyclobalanopsis*, *Diospyros*, *Choerospondias*, *Acitnidia*. The highest area of Siming Mountain in the south would have had a distribution of broad-leaved forest mixed with conifers, composed with some trees in mixed forest B (see Figure 2.3) and an increasing proportion of *Cinnamomum*. There are also *Amygadalus* (wild peaches), *Morus* (mulberries), *Liquidambar* (sweet gum), which could have been used for building timbers in the past.

Environmental research on the sea level change indicates that there have been several fluctuations throughout the Holocene. It rose rapidly in the early Holocene, and kept at high levels until about 5,000 years BC. Part of the coastal plain area was under water during those three millennia. Since around 5,000 years BC, the sea level was relatively lower and a series of low-lying plains was formed (Tao et al., 2006). Wang *et al* (2006) argue that the sea level started to rise again at about 4,000 years BC, and stayed at a high level until 1,500 to 1,000 BC. Li, Mo and colleagues took samples at Tianluoshan for geochemical analysis to investigate the palaeo-salinity at the site (Li et al., 2009, 2010, Mo et al., 2011). The tests revealed three sea level rising events which happened before, during and after the occupation of Tianluoshan. Based on their analysis, the authors also suggested that the invasion of

the sea water could have negative influence to the subsistence, and thus the development of the Hemudu culture. The sea level has been close to the present-day level over the last 3,000 years.

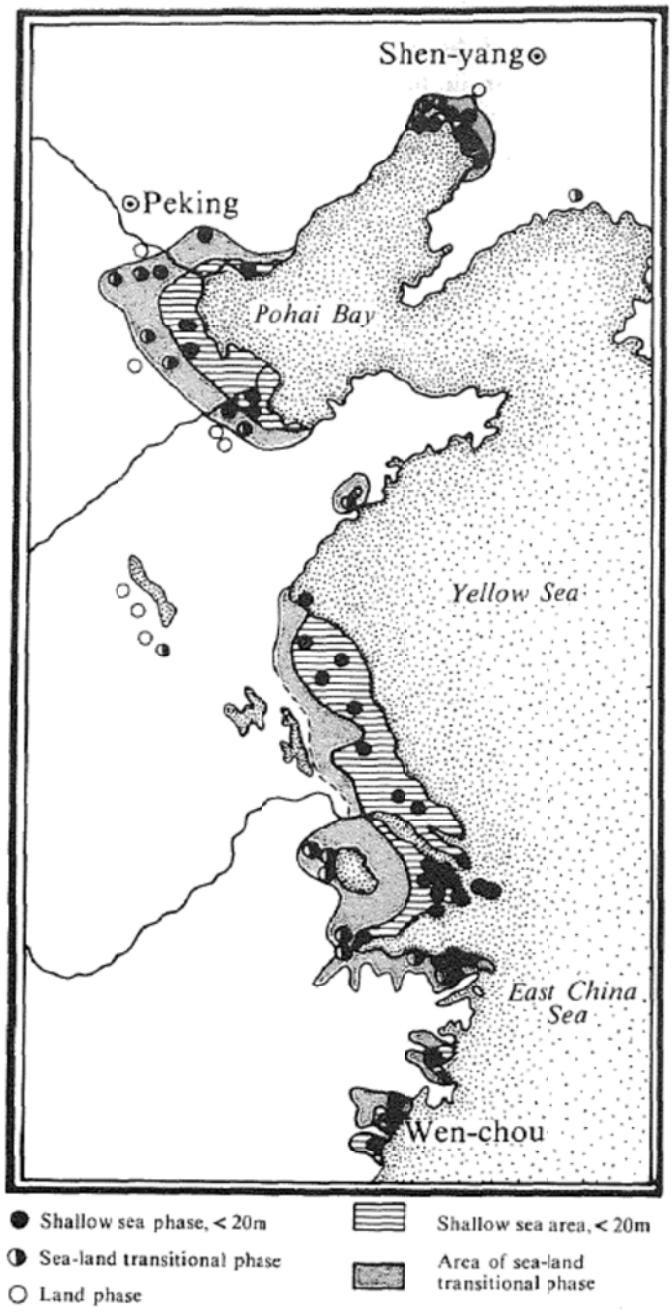


Figure 2.4 Maximum marine transgression during the Holocene in the China Sea, from AGS 1981, no. Ⅰ, p.8. Quoted from K. C. Chang (1986, P73).

In general, the environment and climate changed several times throughout the Holocene. Although employed different methodologies, previous environmental

research share the common perspective that the climate at middle Holocene was slightly warmer and wetter than present conditions in the Ningbo-Shaoxing Plain, and the southern vegetation zones shifted northward accordingly. Besides, the sea level fluctuated and the coastline of the East Sea also shifted throughout Holocene (Figure 2.4). The warmer and wetter climate and environment at mid-Holocene Tianluoshan can also be reflected by the faunal remains (for details see Chapter 7 and 8).

Table 2.1 The chronology of the Neolithic Age in the lower Yangtze River region. Data are summarized from Chang (1986), Zhang and Wei (2004) ,Liu and Chen (2012)

Chronology	Phase	Archaeological culture	Site
8,000 BC	Early Neolithic	Shangshan culture	Shangshan
7,000 BC			Xiaohuangshan
6,000 BC	Middle Neolithic	Kuahuqiao culture	Kuahuqiao
5,000 BC	Late Neolithic	Hemudu culture	Hemudu, Tianluoshan
		Majiabang culture	Majiabang
4,000 BC		Songze culture	Xiaodouli
3,000 BC	Final Neolithic	Liangzhu culture	Fanshan, Yaoshan,
2,000 BC		Maqiao culture	Qianshanyang (post Liangzhu)
			Maqiao

2.3 Cultural background

There have been several theoretical systems to define phases of the Neolithic Age in China. Chang (1986) divides the Neolithic Age into three phase, which are equivalent to early, middle and late Neolithic Age. Phase one lasts from 8,000 to 5,000 BC, when early agriculture emerged. During phase two (5,000 to 3,000 BC), regional Neolithic cultures develop, represented by Yangzhao Culture in the Middle Yellow River Valley, Dawenkou Culture in Shandong and Jiangsu Province, and Hemudu in the Lower Yangtze River. Phase three started from 3,000 BC, when interaction between regions enhanced and civilization emerged. However, it has been nearly thirty years since Chang's overview on Chinese archaeology. During this period, archaeological work has been practised extensively, and more materials have been discovered, expanding our knowledge on Neolithic archaeology in China. On the other hand, as excavation proceeds, the relative research deepens. Chinese archaeology has gradually shifted from reconstructing cultural sequence to a broad study of society since the 1980s. Liu and Chen (2012) classify the Neolithic Age into three phases by the evolution of society based on Chang's division system. In the early Neolithic phase (7,000 – 5,000 BC), sedentism and agriculture arose, and the 'Neolithization' began; in Middle Neolithic phase (5,000 – 3,000 BC), social inequality emerged; the Late Neolithic phase (3,000 BC to 2,000 BC) is symbolized by the rise and fall of early complex societies. Before the beginning of early Neolithic phase, a Pleistocene-Holocene transition era (22,000 – 7,000 BC) is separated based on foraging and collecting subsistence economy. Similar three-phased structure is proposed by many other archaeologists, for example, Zhang (1995) further divides each phase into two stages.

Another important division system is proposed by Yan (1989, P24-37) based on archaeological settlement studies and C^{14} date, and improved by many archaeologists (e.g. Zhang, 2003). According to this theory, the Neolithic Age in China can be divided into five phases, defined successively as early, middle, late, epi- and final Neolithic. Early Neolithic is from the beginning of Neolithic Age to about 6,000 BC. As more archaeological sites are discovered, the upper time limit of Neolithic Age has been pushed back to approximately 9,000 BC. Early potteries are uncovered in this period, and the subsistence economy is still hunting-gathering. Many early Neolithic sites have been excavated in the past two decades, including Xianrendong in the middle Yangtze River, Shangshan in the lower Yangtze River, and Donghulin in the suburb of Beijing. Middle Neolithic generally refers to the sixth millennium BC, when agriculture started to develop and gradually became important in the subsistence economy, such as the Cishan Culture on the North China Plain, and Kuahuqiao Culture in the Lower Yangtze River; but the rate of agricultural development varies evidently between the cultures in the Yellow River region and the Yangtze River region. The Late Neolithic phase lastes from 5,000 BC to 3,500 BC, featuring the further development of agriculture and emergence of social inequality, e.g. Yangshao Culture, Dawenkou Culture and Hemudu Culture. The Epi-Neolithic phase afterwards (3,500 – 2,600 BC) represents the beginning of the Chalcolithic period, when polarization within and between settlements kept developing. The final phase of Neolithic, from 2,600 to 2,000 BC, is generally equivalent to the Longshan Period, represented by the rise of cities across China.

Here only presents two major theories of staging Chinese Neolithic Age. Apart

from them, varied theories have been presented for solving different research questions. For example, some archaeologists suggest to include the Epi-Neolithic phase into Late Neolithic phase (Ren and Wu, 2010), while according to Yan's staging theory the Epi-Neolithic phase is more close to the Final Neolithic phase. The two theories above show obvious differences in staging the Neolithic Age, including the time span and the belonging archaeological cultures of each phase. This dissertation will use Yan's staging system to introduce the archaeological cultures and to discuss the subsistence economy in the study area.

2.3.1 Neolithic cultural sequence in the lower Yangtze River

Following Yan's staging system, the Neolithic Age in the lower Yangtze River can be divided into five phases: Early Neolithic (9,000 – 6,000 BC), Middle Neolithic (6,000 – 5,000 BC), Late Neolithic (5,000 – 3,500 BC), Epi-Neolithic (3,500 -2,600 BC), and Final Neolithic (2,600 -2,000 BC). The representative cultures and sites of each phase are listed in Table 2.1 chronologically.

Early Neolithic Phase (beginning – 6,000 BC)

Hitherto, two early Neolithic sites have been discovered, Shangshan (approx. 9,000 – 6,600 BC) and Xiaohuangshan (approx. 8,000 – 6,000 BC), both located in the valleys among the Siming Mountain (Figure 2.1). Shangshan was excavated from 2001 to 2006, revealing an early Holocene settlement containing dwellings, storage facilities, plant processing tools (grinding stones), and potteries. The cultural remains show distinctive characteristics, hence named as the Shangshan Culture (Zhejiang Province Institute of Archaeology and Cultural Heritage and Pujiang Museum, 2007). Starch and phytolith analysis suggests that the grinding stones are used to process

wild plants such as acorns and Job's tear (Liu et al., 2010). Research on the tempered rice husks and leaves in pottery pieces clearly indicate rice use, and they have been suggested to belong to early cultivated rice (Jiang and Liu, 2006, Zheng and Jiang, 2007). However, lack of other evidence for cultivation or clear evidence of morphological domestication led to debate over the interpretation of these remains, with landscape management for collecting wild rice (Fuller et al., 2008, Fuller and Qin, 2009). At the Xiaohuangshan site, the remains from the lower layers are classified as Shangshan Culture, and those from the upper layers show similarity with Kuahuqiao Culture.

Middle Neolithic Phase (6,000 – 5,000 BC)

The representative culture of middle Neolithic phase is the Kuahuqiao Culture (6,200 – 5,000 BC). The excavation of Kuahuqiao changed the opinion that Hemudu was the earliest site in the lower Yangtze River. A series of excavation in the 1990s revealed large amount of remains at Kuahuqiao, including pottery, lithics, bone tools, and varied animal remains. Thanks to the waterlogged conditions, abundant organic remains were preserved. An important finding at Kuahuqiao is an incomplete dugout canoe, with working tools and remains from processing discovered near it. As it is narrow and shallow, this canoe is possibly made for navigating rivers and lakes.

Zooarchaeological and archaeobotanical research indicates a hunting-gathering subsistence pattern with some food production. Animal bones of diverse species were collected, ranging from fish to large terrestrial mammals. According to the researchers, dog and pig were domesticated animals, but the Kuahuqiao people were still mainly relying on wild animals as meat resource (Yuan and Yang, 2004). Study on

botanic remains suggested that wild resources are emphasized, while rice cultivation might have been established (Zheng et al., 2004, Zheng and Jiang, 2007). Rice remains included a minority of domesticated forms and fit as precursors on the evolutionary trajectory to domesticated rice seen on later sites, in terms of grain dispersal and grain size (Fuller et al., 2010, 2014).

Late Neolithic Phase (5,000 – 3,500 BC)

The representative culture of Late Neolithic phase includes Hemudu culture and Majiabang culture. The Hemudu culture is represented by the type site Hemudu which was discovered in the 1970s, and the newly and thoroughly excavated Tianluoshan (described in detail below). There are also a series of sites of Hemudu culture on the Ningbo-Shaoxing Plain, such as Xiangjiashan and Zishan (Figure 2.1); sites of this period are also found on the Zhoushan archipelago. In the Lake Taihu region (north part of Lower Yangtze River region), the middle Neolithic is represented by Majiabang culture, a parallel culture with Hemudu culture (Chang, 1986, P192 - 233). The Majiabang culture and Hemudu culture are geographically separated by the Hangzhou Bay and Qiantang River in between. Many sites of this phase are preserved due to waterlogged conditions, providing plenty of organic materials. Detailed introduction of Hemudu culture shall be presented in the next section.

The Majiabang Culture is represented by a number of sites (≥30) surrounding Lake Taihu, such as Majiabang, Luojiajiao, Caoxieshan and Weidun. Sites of Majiabang Culture were first discovered in the 1950, but only confirmed as an independent culture in late 70s. Ceramics are predominantly red, black and grey; there are also a few white ceramics. A significant feature of the Majiabang Culture is

that tools and accessories made of bone, antler and tooth play an important role at the settlements. Studies on subsistence economy suggest a compounded pattern of hunting, gathering, and farming. Patched paddy fields of late Majiabang culture are discovered at Chuodun and Caoxieshan (Gu et al., 1998, Fuller and Qin, 2009) Domestic animals include dog and pig (Zhang, 1981, Huang, 1978). Archaeological materials suggest that Hemudu and Majiabang culture had interactions on each other: in the earlier phase, Hemudu culture had a stronger influence on Majiabang culture, while in the late phase when Hemudu culture started to decline, the influence of Majiabang on Hemudu culture strengthened.

(a)

(b) (c)

Figure 2.5 Paddy field. (a) low-laying patched paddy field at Chuodun, Late Majiabang phase; (b) and (c) paddy fields at Chenghu, Songze culture (Ding, 2004).

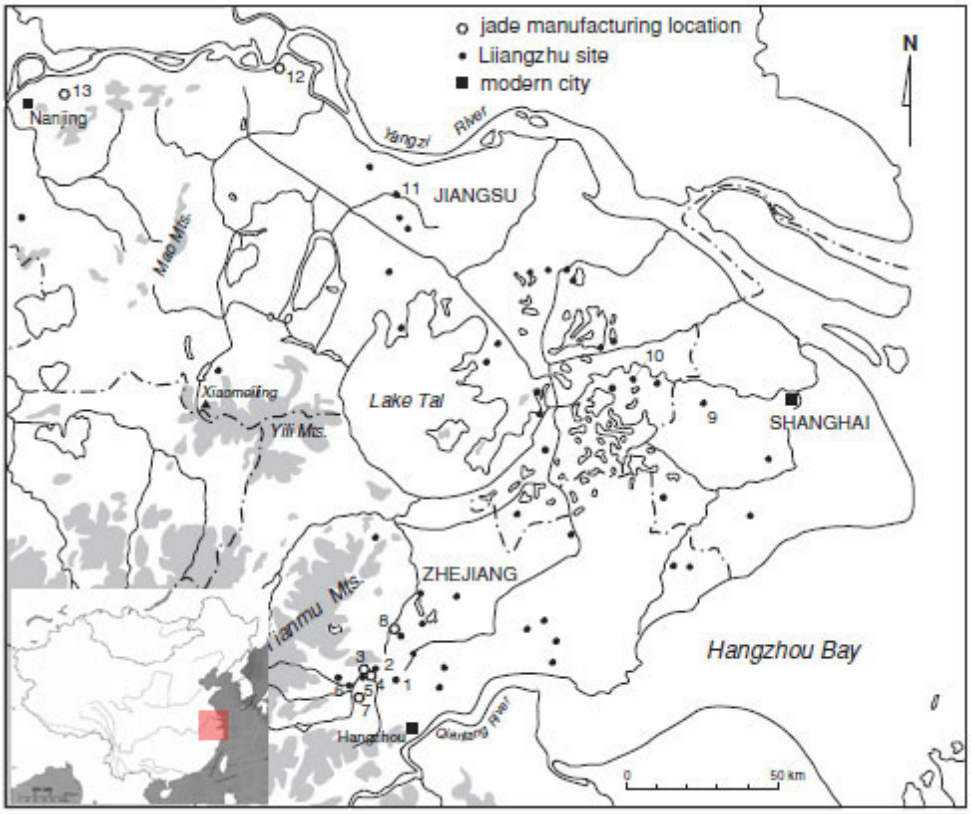
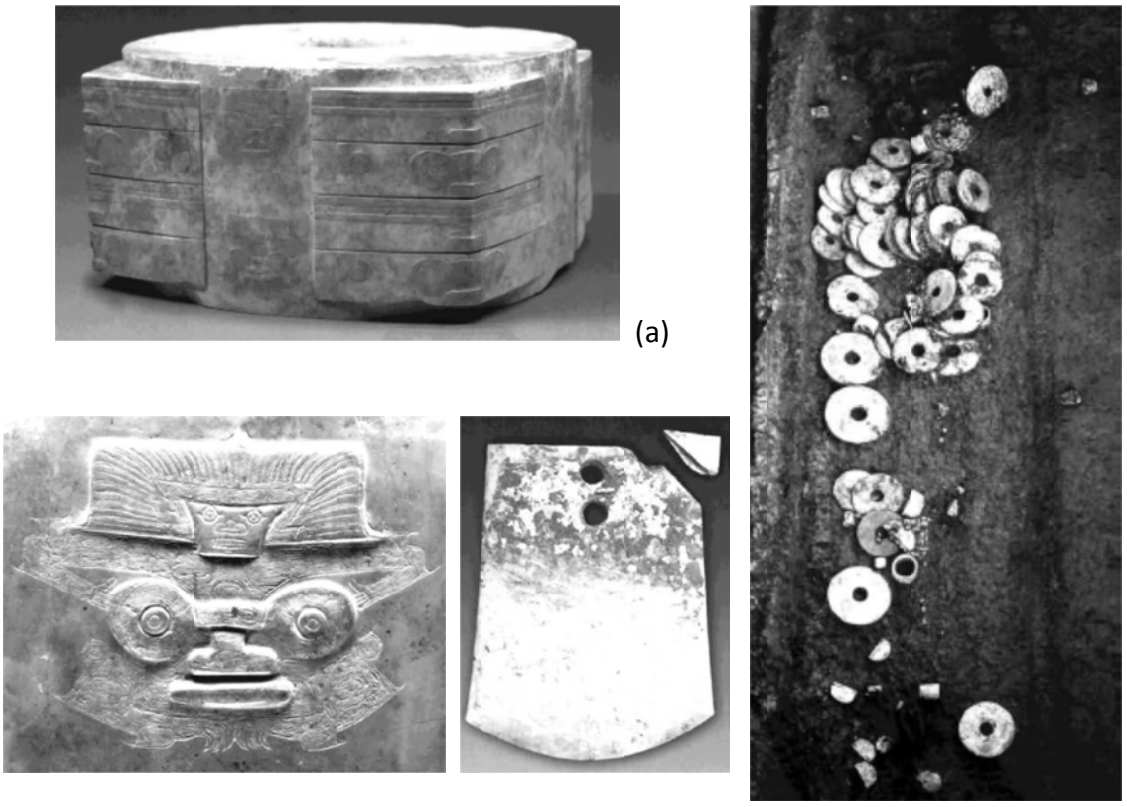


Figure 2.6 The distributional area of Liangzhu culture on the Yangtze River delta. The major Liangzhu sites are plotted as follows: 1, Liangzhu; 2, Yaoshan; 3, Lucun; 4, Ansi; 5, Mojiaoshan, Fanshan; 6, Huiguanshan; 7, Wenjiashan; 8, Yangdun; 9, Fuquanshan; 10, Zhaolingshan; 11, Sidun; 12, Mopandun; 13, Dingshadi. Reproduced from Figure 7.11 in Liu and Chen 2012.

Epi-Neolithic (3.500 – 2,600 BC)

The Epi-Neolithic phase is represented by the Songze Culture. The Songze Culture that arose in the Lake Taihu region after the decline of the Majiabang Culture, and spread to adjacent areas during its prosperity. Radio carbon data indicate that the Songze Culture lasted from 4,000 BC to 3,300 BC. Pottery vessels are decorated with various patterns; cut-out and carved geometric patterns are the most popular and characteristic ones among all of them. The cemeteries of Songze Culture display a sophisticated custom, including burial location, the arrangement of funerary objects, and the use of jade. The social groups within the Songze Culture demonstrate slight hierarchy, but unlike the Liangzhu Culture afterwards, the cemeteries do not reflect

obvious social differentiation between social groups yet (Qin, 2003). Domestic rice and paddy field have been uncovered from Songze sites, e.g. Chenghu (Gu et al., 1998, Ding, 2004)and the area of a single paddy field enlarged significantly comparing to the patched fields of the previous Majiabang Culture (Figure 2.5). Hunting is the major element in the subsistence economy of Songze culture, but the proportions of wild animals may have decreased, replaced by domesticated animals such as pig and dog. A large number of net sinkers have been uncovered, indicating that fishing may have played an important part in the Songze subsistence (Ren and Wu, 2010).



(a) (b) (c) (d)

Figure 2.7 Jade objects from Liangzhu culture: (a) 'cong' tube; (b) the human-beast motif which appears frequently on cong; (c) 'yue' axe; and (d) 'bi' discs in burial M23 at Fanshan at excavation (Zhejiang Province Institute of Archaeology and Cultural Heritage, 2005).

Final Neolithic (2,600 – 2,000 BC)

Liangzhu Culture in the Final Neolithic phase is well known for its exquisite jade artefacts and sophisticated social structure represented by high-class burials ever since its first discovery in the 1930s. So far, approximately 200 sites of the Liangzhu Culture have been reported, mainly distributing on the Yangtze River delta region, an area between Yangtze River and Qiantang River/Hangzhou Bay (Figure 2.6). Radio carbon data indicate that the Liangzhu Culture was active from 3,300 to 2,000 BC. Liangzhu culture is mainly characterized by black pottery vessels, and jade artefacts of several varieties, such as 'cong' tubes, 'yue' axes, and 'bi' discs (Figure 2.7). According to the cemetery materials, distinct social hierarchy started from the Liangzhu period: the large tombs contain hundreds of burial objects, whereas the small ones barely have any. Agriculture developed greatly during the Liangzhu period, represented by a series of farming tools. However, the complex hierarchical society came to its end in the late third millennium BC. Although a few factors of Liangzhu culture can be found in the following Maqiao culture, its prosperity has never been reproduced in this region. Archaeologists discuss that the sudden collapse could be caused by internal social crises, an invasion from the north, or natural catastrophe (Stanley et al., 1999, Zhao, 1999, Song, 2004).

In general, the chronological sequence on the lower Yangtze River region is much simpler comparing to that of the Yellow River region. Geographically, the lower Yangtze River region can be further divided into south and north areas by the Qiantang River and Hangzhou Bay. The natural division weakens the communication between two areas, so the cultural sequences tend to develop independently. The

earliest cultures appeared in the mountain valleys in the south area (Shangshan and Xiaohuangshan) and gradually moved to the lowland plains (Hemudu) in the late Neolithic phase. This area was barely used after late Neolithic. Meanwhile, the cultural sequence in the northern area, i.e. the Lake Taihu region, started since late Neolithic, developed from Majiabang Culture through Songze Culture and finally flourished in the Liangzhu Culture. Study on the material culture suggests that communication was practised during the coexistence of Hemudu Culture and Majiabang Culture.

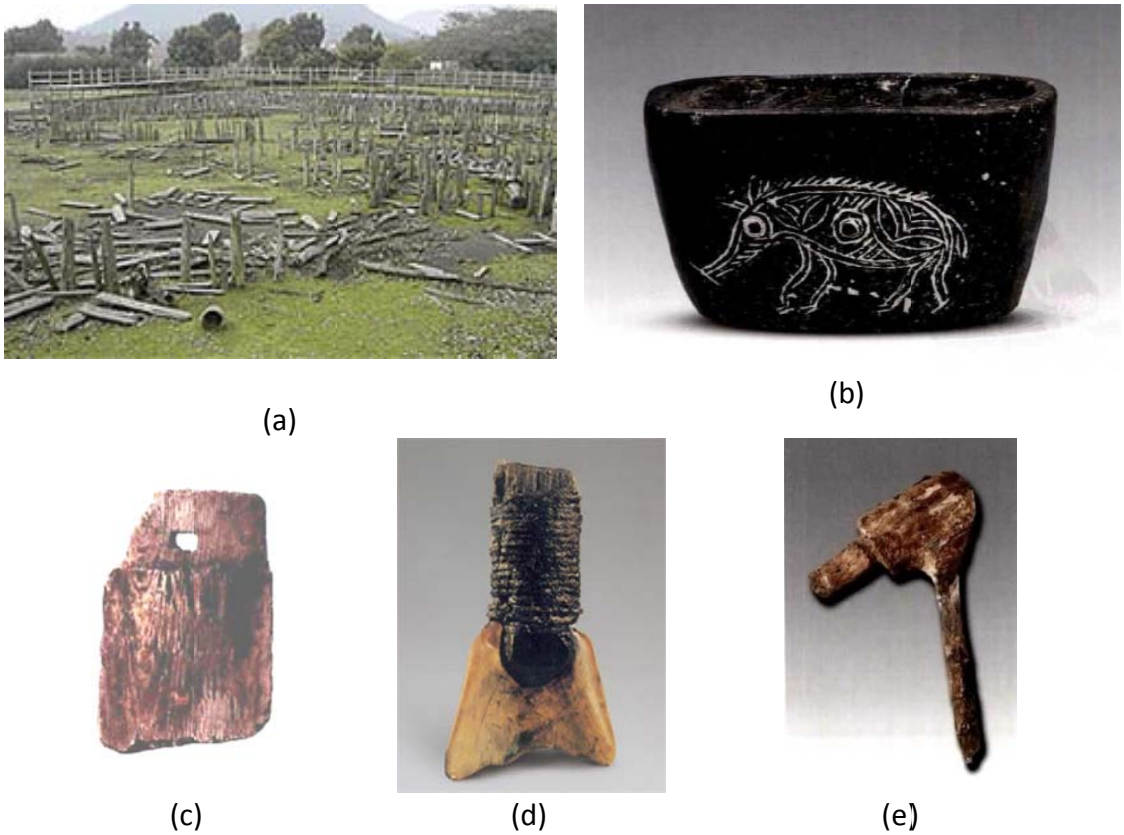
As the basis of subsistence interpretation, a review of the cultural sequence helps to understand the development of subsistence economy. On the other hand, the shift of archaeological cultures may reflect on subsistence to some extent. Therefore, not only natural factors, cultural issues will also be considered in the discussion sections of this dissertation.

2.3.2 An overview of the 'Hemudu Culture'

Hemudu culture sites are mainly distributed in the east coastal area of the Lower Yangtze River region, and are particularly grouped along the Yao River on the Ningbo-Shaoxing Plain. Sites of Hemudu culture can be found on the Zhoushan archipelago in the East Sea. Until now, over 50 sites of Hemudu culture have been discovered, and ten important sites are plotted in Figure 2.1.

Hemudu culture is named after the Hemudu site in Yuyao County, only 7 km away to the southwest of Tianluoshan. Two seasons of excavation were practiced in the 1970s, 1973-1974 and 1977-1978, altogether revealing 2630m^2 of the site. Four thick layers of archaeological deposits contain large quantities of artefacts, floral, and

faunal remains. The most significant findings are the wooden pile-structured dwellings, in which piles and timbers are arranged in rows (Figure 2.8 a). Reconstruction suggests that these are originally belong to elongated rectangular houses (approx. 23 metres long 7 metres deep) supported by wooden stakes, so that the gap underneath can raise the houses up away from humidity and dangerous animals (Figure 2.9). For construction skills, the mortise and tenon technique is employed to connect timbers (Figure 2.8 c). Other construction features include a water well and storage pits filled with acorns and water chestnuts (Zhejiang Provincial Institute of Cultural Relics and Archaeology, 2003).



(a) (b) (c) (d) (e)

Figure 2.8 Feature and artefacts from Hemudu. (a) Base of pile-structured dwelling; (b) black pottery pot decorated with pig image; (c) construction component with mortise-tenon joint at one end; (d) bone "spade (Si)" bound to wooden handle by rope. Photos are from Hemudu excavation report (Zhejiang Provincial Institute of Cultural Relics and Archaeology, 2003).

Figure 2.9 A reconstruction of the wooden pile-structured dwelling at Hemudu. This photo was taken at the Hemudu Museum.

Pottery is mainly black and grey, tempered with fiber and/or sand; some of them are decorated with plant and animal designs (Figure 2.8 b). Among all the bone tools from Hemudu, the most representative is spade, or named 'Si'. Bone spades are made from scapulae of large mammals, usually water buffalos and sambar; occasionally ilium is used. The scapula or ilium is drilled, trimmed, and tied to a wooden handle with ropes as shown in Figure 2.8 (d). Plenty of wooden artefacts are found at Hemudu due to the waterlogged environment, such as handles (Figure 2.8 3), paddles, spear, and crafts.

It also provides large quantity of materials for the study of subsistence economy. There is a thick layer of mixed rice husks, chaffs, leaves and charred rice in the upper part of the 4th layer. It was estimated that these remains represent about 120 tons of rice (Yan, 1982). A great number of animal bones were collected during excavation. Research indicates that domestication started to develop while wild resources were

still emphasized. Details about relative research on subsistence economy shall be discussed later in this chapter.

Geographically, the Hemudu culture is a highy regional archaeological culture which is restricted in an elongated plain area in the lower Yangtze River region. The distribution pattern is so distinctive that it differs from the sites either earlier (Figure 2.1, 11 - 13) or later (Figure 2.1, 14 - 17) than Hemudu sites. The early Neolithic period sites such as Shangshan, Xiaohuangshan and Kuahuqiao, are located in valleys among mountains with higher elevations; while the later sites are found in the eastern area, rarely in the Yao River valley. Archaeologists have been discussing the origin and spread of the Hemudu culture, but have not yet established a secure theory. Many researchers consider that as the Hemudu culture declined it became influenced by other adjacent cultures and then merged into a new culture (Wang, 1991, Li, 2010). There is also a theory suggesting that the Hemudu people gradually migrated to the islands in the East Sea due to the rise of sea level, and possibly moved to southeast China or even Taiwan (Jiao, 2009, Jiao et al., 2011).

Material culture indicates that the Hemudu culture shares commonalities with the parallel Majiabang culture in the Lake Taihu plain. Summarizing from the indications of material culture, Wang (1991) suggests that these two cultures had interactions during the middle Neolithic Age: in the early phase, Hemudu culture had an influence on Majiabang culture; and in the late phase as Majiabang culture grows stronger, Hemudu culture received influences from it. However, there has not been enough archaeological evidence to support either theory. It requires further investigation on the intriguing Hemudu culture.

2.3.3 A review of Tianluoshan

Tianluoshan is located in the same valley as Hemudu, only a few kilometres away from each other. The site was found in 2001 and several seasons of excavation have been undertaken since 2004. Figure 2.10 shows the major excavation area of Tianluoshan, which is now covered under a shelter dome to turn the site into an open air museum. It is estimated through drilling investigations that the whole Tianluoshan site covers about 30,000 m^2. Radiocarbon dates indicate that Tianluoshan was occupied approximately from 5,000 to 4,000 Cal BC (Wu et al., 2011).

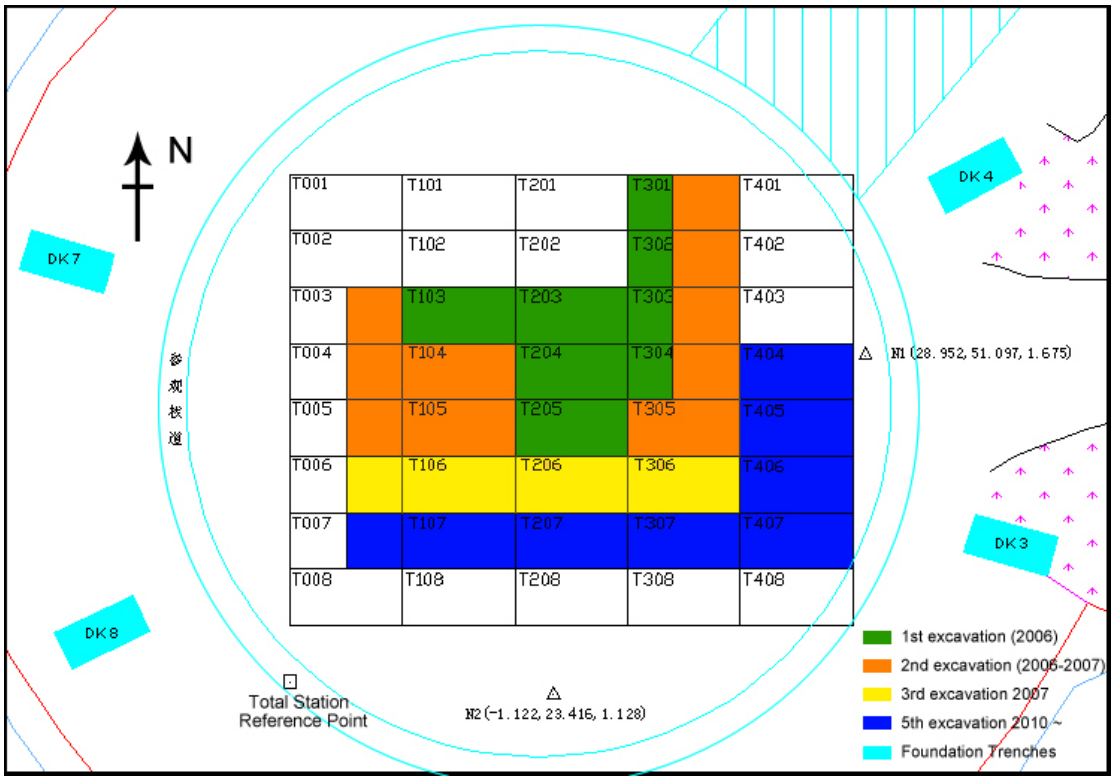


Figure 2.10 The plan of Tianluoshan, showing the areas of the four seasons of excavation. The rea of the fourth excavation is beyond this map. Each trench is 10 m × 5 m. Trenches DK1-8 are excavated to build the foundation of the shelter.

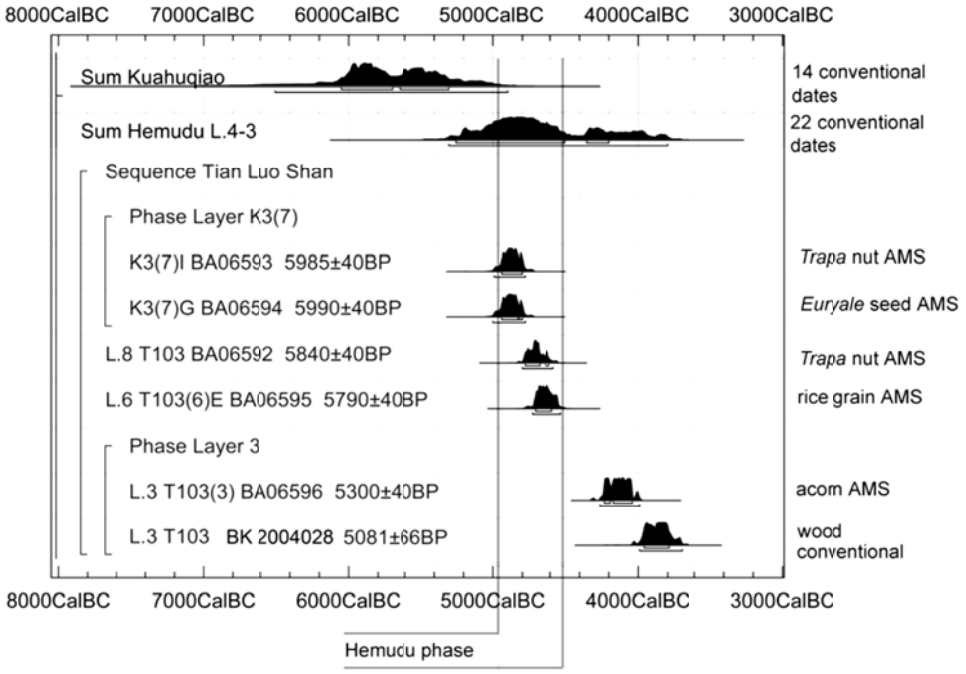


Figure 2.11 The radiocarbon dates of Tianluoshan (Wu et al., 2011). The earliest radiocarbon date of Tianluoshan comes from the K3(7) samples (layer 7 in trench DK3), about 4,900 Cal BC, followed by layer 8 and 6 in the main excavation area, about 4,800 to 4,700 Cal BC. Layer 3 is dated to approximately 4,200-4,000 Cal BC.

Eight layers are recognized from the deposition, numbered as layer 1 to 8 from top to bottom; layers 3 to 8 among them belong to the Hemudu period. According to the radio carbon date and the study of artefacts, all stratigraphic layers can be grouped into three stages: early Hemudu culture, represented by layer 8 and 7; subsequently layer 6 and 5 as the middle Hemudu culture stage; and the late Hemudu culture, represented by layer 4 and 3. However, only a few trenches have covered the excavation of all eight layers; most of them currently stop at the bottom of layer 6 for the conservation of the wood constructions. Eight 10 m × 5 m trenches in the surrounding area, labeled as DK1 to DK8, were excavated to build the foundation of the shelter (Figure 2.10). Rich plant remains were uncovered in layer 7 of DK3, and many of them were found in storage pits. A pit (numbered as H1) filled with fish bones was found in the same layer of DK3. Although it follows the same

numbering system as in the central excavation areas, the radiocarbon dates indicate that layer 7 is even earlier than the earliest stratum (layer 8) in the main excavation area (Figure 2.11).

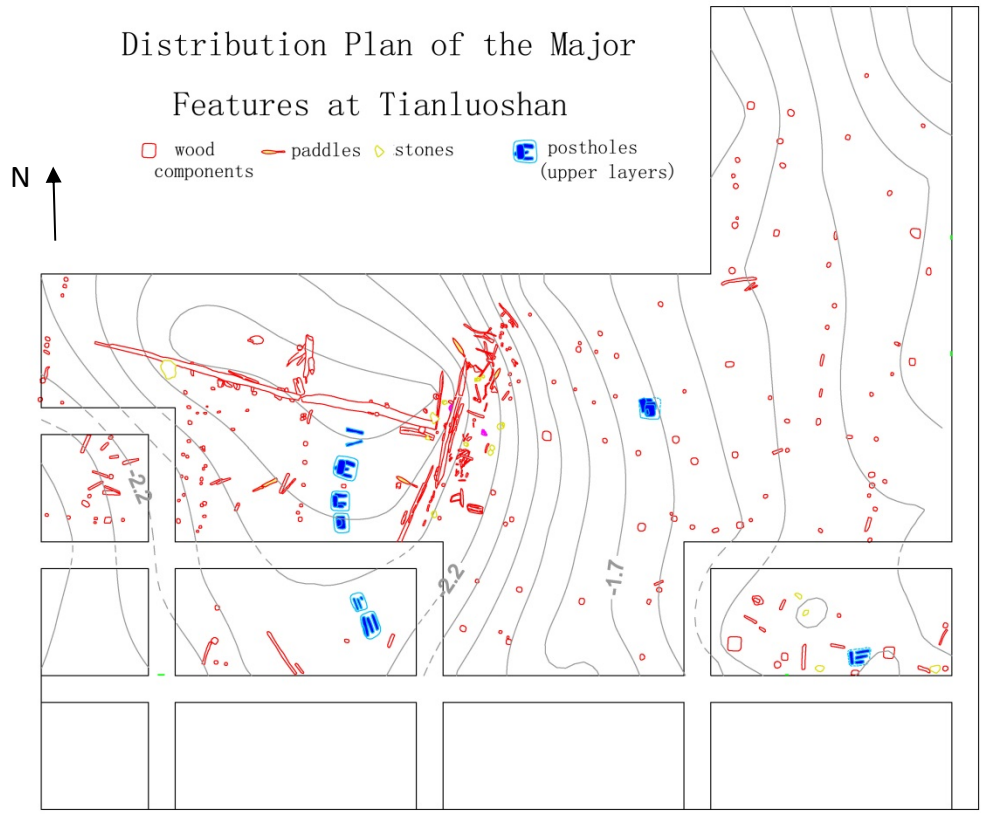


Figure 2.12 Distribution of the major features at Tianluoshan, showing only the main excavation area in 2007. The features marked in this plan include wood components, stones, and postholes.

The base of the wooden constructions was uncovered in the early and middle Hemudu layers, including pile-dwellings and fences. A series of fences were built at the edge of the low-lying area, the same place where several paddles have been found (Figure 2.12 and Figure 2.13). The log lying aside is considered as a single-log bridge across the stream that runs through the site (Sun, 2011). On the higher-ground to the east part, posts were arranged in rows, showing the location of the pile dwellings (Figure 2.12). The retrieved remains include pottery, lithics, jade, bone

tools, animal and plants remains, resembling those from Hemudu. Organic materials are preserved well due to the waterlogged environment, such as the pile-dwelling base, wooden objects, and other plant remains. Bones, for example are barely weathered.

Systematic sampling was applied in the second season of excavation for the purpose of archaeobotanical research. Fine sieving was also used in the second season as well as the seasons afterwards, providing more materials for studying subsistence, including many seeds and most of the fish bones. The outcome has inspired many projects regionally to employ fine sieving in excavation.

Most importantly, the excavation at Tianluoshan uncovered abundant materials for re-studing the Hemudu Culture. It is the most complete assemblage since the discovery of Hemudu, and the retrieving of small remains which were generally overlooked further enlarged the study sample. A project of integrated studies on the natural remains from Tianluoshan was set up in 2006, which was pioneering for archaeological studies in China. The scientific research agenda included the fields of chronology, palaeoenvironmental reconstruction, microbiology, archaeobotany, zooarchaeology, ichthyology, and stable isotope analysis. As was indicated in the previous section, palaeoenvironmental research outlines a framework of warm and humid environment with slight fluctuations at the site (Mo et al., 2011). Change of sea level during the occupation of the site is proven by both paleosalinity research and analysis of diatoms, indicating that Tianluoshan might have been very close to the sea for a period (Li et al., 2010, Kanehara and Zheng, 2011, Mo et al., 2011). Phytolith analysis suggests that the ratio and density of rice phytoliths are both very high at Tianluoshan, indicating the existence of rice cultivation (Udatsu and Zheng,

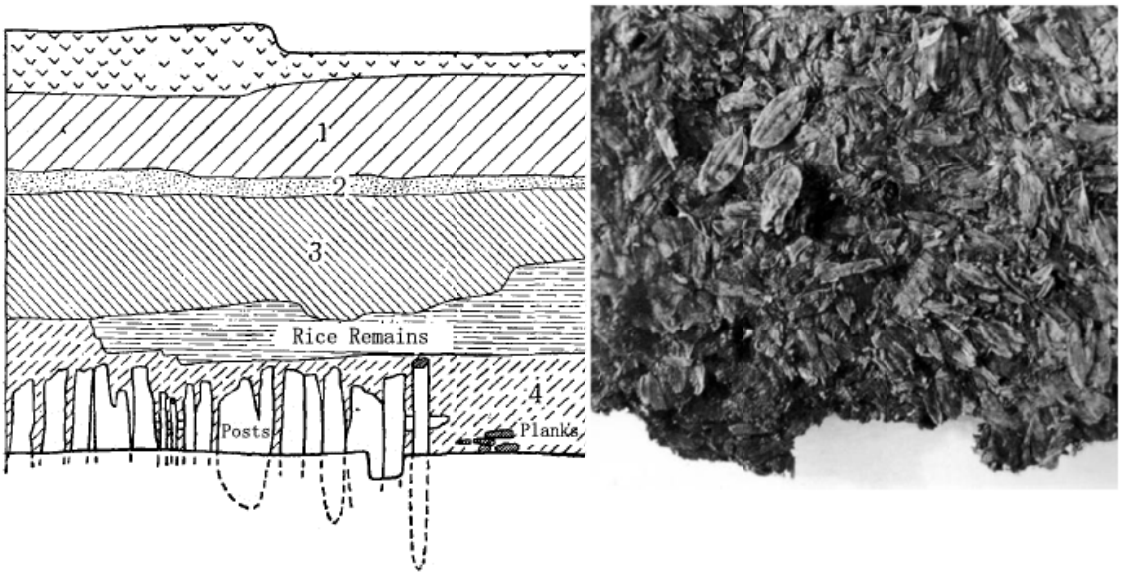
2011). The subsistence economy at Tianluoshan is discussed from the plant and animal remains, and the results will be presented in the next section, alongside other research.

Figure 2.13 Bird view on the low-lying western part of the excavation area, showing details of the fences and log.

2.4 Research on the subsistence of Hemudu Culture

Before the discovery of Tianluoshan, the understanding of Hemudu Culture was primarily based on the remains from Hemudu site. According to the preliminary report (Zhejiang Natural Science Museum, 1978) and the final report (Zhejiang Provincial Institute of Cultural Relics and Archaeology, 2003), animal and plant remains accumulated densely in the Hemudu Culture deposits, especially in the Early Hemudu Culture layer (layer 4). Rice, among all the remains, has been discussed most intensively. Most of the rice remains are straw, leaves, and husks; rice grains are found occasionally (Figure 2.14). It was estimated that the thick layers of rice remains

might be the debris of 120 tons rice (Yan, 1982), although these did not represent a single depositional event judging by the stratigraphic photographs. Dog, pig, and water buffalo among all the species are identified as domesticated animals. Accordingly, Hemudu is considered as a developed agricultural society (Zhejiang Provincial Institute of Cultural Relics and Archaeology, 2003, P371-375). It was accordingly often presented as an example of early intensive rice agriculture in many texts (e.g.Chang, 1986, Bellwood, 2007, Higham, 1995).



(a) (b)

Figure 2.14 Underground profile of Hemudu (a) and detailed view on the rice remains (b). 1-4 in graph (a) are the four strata of the cultural deposits. The thick layer containing rich rice remains lies between layer 3 and 4. Timber posts are shown planted under layer 4.

Soon after the excavation, the rice remains were identified as domesticated rice of the *hsien* variety, i.e. *Oryza sativa subsp. indica* (You, 1976). Discussions over the following twenty years has focused on identifying the variety of rice, and whether they were of the *indica* variety or the *japonica* variety, using different measurements. Hemudu and the lower Yangtze River have been considered as the centre for rice agriculture in the world (Bellwood, 2005). The discussions of Hemudu rice have also

deeply influenced the research of Neolithic agriculture in China. As Hemudu was considered as a developed agricultural society, archaeologists began to pursue the origin of rice domestication from early and middle Neolithic sites. A common opinion is that rice domestication started about ten millennia ago, based on various rice finds such as the rice husks found in pottery debris from Shangshan, represented by Liu and colleagues' study (Jiang and Liu, 2006, Liu et al., 2007b). Meanwhile, Fuller, Qin and colleagues, suggest that the domestication of rice was still in progress from middle Neolithic to the earlier phase of late Neolithic (Fuller et al., 2007, 2009).

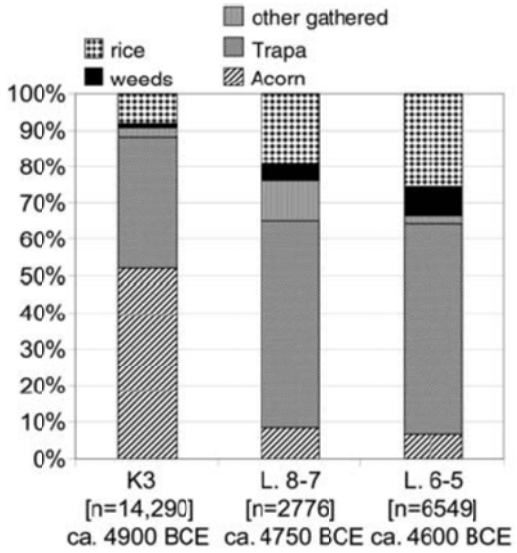


Figure 2.15 Proportion of plant remains from sieved samples from the three periods at Tianluoshan (Fuller et al., 2009, Figure 2).

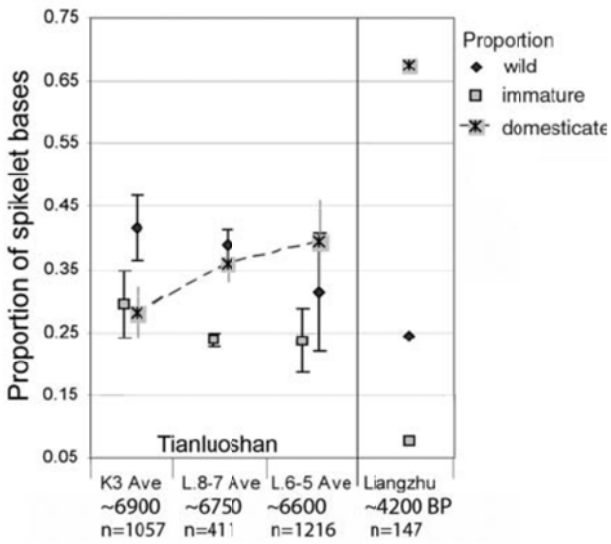


Figure 2.16 Proportions of wild, immature, and domesticated rice spikelet based from three sequential periods at Tianluoshan (Fuller et al., 2009, Figure 4).

Apart from the rice remains, a variety of fruits and seeds of wild plants are also found at Hemudu, including acorns (*Quercus* sp.), water chestnuts (*Trapa* sp.), foxnuts (*Euryale ferox*), peaches (*Amygdalus persica*) and jujube (*Choerospondias axillaris*); many of them are found in storage pits (Zhejiang Provincial Institute of Cultural Relics and Archaeology, 2003, P216-218, Qin et al., 2006). Restricted by

retrieval methods, smaller seeds and fruits were not collected. The information on plant remains was supplemented by the many more complete samples from Tianluoshan. More than 50 species have been identified from the floral assemblage. There are four predominant plant food resources: acorns (including deciduous *Lithocarpus* and evergreen *Cyclobalanopsis* types), water chestnuts, aquatic foxnuts and rice. Acorns and wild aquatic plants have been stable food resources for a long time, at Tianluoshan, while rice appeared to be a supplementary resource. However, the proportion of rice increases from 8% to 24 % and that of acorns declines remarkably (Figure 2.15). The findings of acorn storage pits may indicate that acorns were used as backup food, and then gradually abandoned. On the spikelet bases, the proportion of domesticated type increases (Figure 2.16), indicating that rice domestication was in progress (Fuller et al., 2009). The finding of ancient field areas where rice grew and farming tools found (Figure 2.17) also supports the conclusion that rice was an important food with targeted production practices.

Very rich animal remains were revealed during excavation at Hemudu, but only larger bones and specimens which can be identified specifically to species were collected and studied. From the record, the NISP and MNI are probably several times more than those of the Tianluoshan fauna. The study of the animal remains focused mainly on identification and measurement of crania. A total number of 61 species were identified, including 3 invertebrate, 10 fish, 6 reptiles, 8 birds, 31 wild mammals, and three domesticated animals (Zhejiang Provincial Institute of Cultural Relics and Archaeology, 2003, P154-216) . The fish species were identified mainly from teeth (e.g. *Carcharhinus* sp., *Cyprinus* sp., and *Carassius auratus*), scute (e.g. sturgen), and skeletal parts including dentary, opercular, premaxilla and pectoral fins.

As a pioneer study of fish remains, this case study provided references for the following studies. However, it featured qualitive rather than quantitative analysis, so the relative importance of the fish species in the faunal assemblage was still unknown. Although lacking statistical analysis, the researchers notified that the number of fish, reptiles and invertebrates was much larger than mammalian remains, hence might be the main food resource. It is the first case study of fish remains from

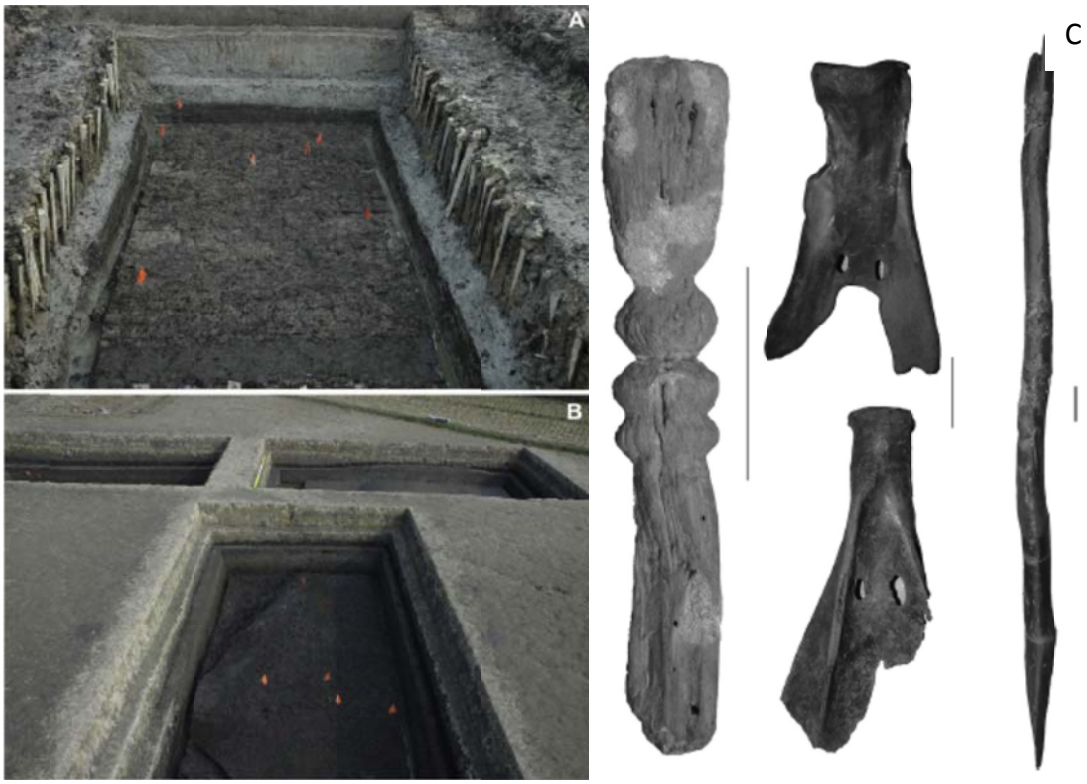


Figure 2.17 Two layers of rice growing fields at Tianluoshan, and the relevant farming tools. A is the early rice field dated to 4,650 – 4,490 BC, lying 2.8 m deep under the surface. Wooden pegs are used for preventing collapse of the walls. B is the later field dated to 3,340 – 3,090 BC. Red flags mark the locations where pottery sherds are found. C shows the farming tools found at Tianluoshan, from left to right, they are wooden knife, bone spades, and wooden dibble. Spades are found within the settlement, and the other two in the paddy field. Scale is 5 cm. Pictures quoted from Zheng et al (2009).

Part of the mammalian and fish remains from Tianluoshan have been studied and the results are presented in the *Integrated Studies on the Natural Remains from Tianluoshan* (2011). The mammalian remains retrieved in the first excavation in 2004

were studied by myself. Although limited by retrieval strategy only larger bones are collected, this assemblage generally reflects the composition of the mammalian fauna at Tianluoshan. About 20 categories of mammals are identified to family, genus and species, most of which are wild animals. The dominant species include sika deer, muntjacs, sambars, and pigs; the proportion of pigs is much lower than the others. The fish remains from a fish bone pit H1 in DK3 have been studied by ichthyologists Nakajima and colleagues. They (Nakajima et al., 2011, Nakajima et al., 2010a) suggests that H1 contained nearly 1,600 fish, and 88.1% of them are crucian carp (*Carassius auratus auratus*). It can be inferred from body length reconstruction that these fish were captured during a short period in late spring. They also assumed that fish were stored in pit as a way to process and keep fish.

These pioneer studies provided a general view of the animal subsistence economy at Tianluoshan, such as what animals were present at the settlement, and what the relative importance was. However, these studies had many aspects to be improved. First, the sample size was relatively small. The study materials only included a fraction of the animal assemblage: the mammal remains from the excavation in 2004, and the fish remains from a single pit. Since a large number of animal remains, especially fish remains, had been retrieved from the stratigraphic layers in the next few excavation seasons, the conclusions shall be improved accordingly. Second, Nakajima and colleagues' research has a methodological flaw, that the fish species and MNI were identified only from pharyngeal bones and teeth, yet the other skeletal parts were not studied. This method works fine in the research of cyprinids, wich have only a few pharyngeal teeth on each individual. However, snakehead, for instance, each has about 1,200 tiny teeth (Nakajima et al., 2011),

which usually fall off the jaws, and are too small to retrieve. Clearly, by using this method, the number of cyprinids could be exaggerated, and the other fish could be overlooked. Third, the interpretation of the fish bone pit requires more archaeological analysis. Nakajima and colleagues considered the fish remains from H1 a resemblance of the entire fish assemblage, and discussed the fish exploitation at Tianluoshan. However, the residue in a pit could be accumulated very quickly. H1 might simply represent a single fishing season, rather than a year-round event.

In order to overcome these issues, the sample size for this project was enlarged greatly. All fish remains, including both teeth and bones from the stratigraphic layers, were carefully studied, for the purpose of revealing a long-term process of fish exploitation at Tianluoshan.

This integrated research on natural remains contributes to revisiting the subsistence economy of the Hemudu Culture properly. As is mentioned before, the Hemudu Culture was considered as a developed agricultural society for decades, which finally became a concept in textbooks. However, if we analyse the data carefully, we will find that it is still too early to come to such a conclusion. Qin and colleagues(2006) reviewed Hemudu subsistence soon after the publication of the final excavation report. By reviewing the natural remains, tools, and relevant research on archaeobotany, zooarchaeology, and genetics, they suggested that Hemudu was a hunting-gathering society which lived mainly on foraged nuts and hunted animals. Based on this conclusion, the discussion of the rice evidence and how to study rice domestication was stimulated further in the following years (Fuller et al., 2009, Fuller and Qin, 2010, Fuller, 2011).

For decades, the viewpoint about rice domestication has influenced not only the

discussion on the use of plant resources, but also the themes in animal domestication. The identification of domesticated water buffalos and pigs was more or less related to it. *Bubalus mephistopheles* was first identified by Teilhard De Chardin and Young (1936) at Anyang site, and then was found widely distributed at Neolithic and Bronze Age sites across China. In the lower Yangtze River region, the remains of *B. mephistopheles* have been found at sites from middle Neolithic (Kuahuqiao) to final Neolithic phase (Liangzhu and Maqiao). As water buffalos are used for traction in traditional rice agriculture, the co-existence of rice and water buffalo remains at Hemudu and other Neolithic sites encouraged the theory that water buffalo was domesticated indigenously in China, *B. mephistopheles* inferred as the ancestor species (e.g. KC Chang 1986: 211; Bellwood 1997: 208). The large ploughs found at Liangzhu sites seemed to have made this theory unquestionable. The domestication of *B. mephistopheles* has not been questioned until recently when ancient DNA test proves that *B. mephistopheles* is an indigenous wild species and has no direct affinity with the modern domesticated water buffalos (Yang et al., 2008). On the other hand, the concept that Hemudu is a developed agriculture society has made the interpretation of pig remains toward domestication; the use of wild boars tends to be ignored. Pig domestication was a foregone conclusion for Hemudu (e.g. KC Chang 1986: 211; Bellwood 1997: 208), while domestication was inferred for the earlier middle Neolithic (Kuahuqiao Culture) (Luo, 2007). Recent moloeculr genetics on Chinese pigs and ancient DNA point to a single population being domesticated, amongst many geneteic haplogroups of Chinese wild boar, and that this was established in Yellow River Neolithic sites (Larson et al., 2010). This would seem to imply that domesticated pigs spread from one area raising new questions about

whether was likely to be the Lower Yangtze or not. This controversial issue shall be further investigated in Chapter 8.

2.5 Conclusion

This chapter summarizes the environmental and cultural settings of the Tianluoshan site and the lower Yangtze River region. In general, the geomorphological setting has been stable for millions of years, but the climate changed several times in Holocene. It was warmer and wetter in mid-Holocene when Tianluoshan was occupied, and the vegetation differed accordingly. The sea level also fluctuated. Diatom and salinity research suggests that sea level raised once during the Hemudu period, indicating that Tianluoshan, as well as Hemudu, was once close to the sea.

The Neolithic cultural sequence in Chinese has been built up after a century's archaeological work. The lower Yangtze River region experienced a complete sequence spanning from early Neolithic to final Neolithic phase. It can be described as a Shangshan-Kuahuqiao-Hemudu/Majiabang-Songze-Liangzhu timeline. As an important cultural centre in China, this region has experienced both great prosperity and sudden collapse. It is also considered as the origin area for rice agriculture. The lower Yangtze River is also well-known for the sophisticated jade manufacturing and ritual use in the final phase of Neolithic Age, the Liangzhu Culture.

The review of the cultural sequence in the study area aims to highlight the importance of Hemudu Culture to Chinese archaeology, especially the research on the development of subsistence economy. The Hemudu Culture is a very important section in the cultural sequence in the lower Yangtze River region. First of all,

archaeologists are able to study the constructions and the building technologies from the well-preserved construction components. Chinese culture has a tradition of building up wood-structured (or bamboo and other plant materials) dwellings, but the dwelling components are hardly preserved, leaving only postholes, and fragments of burnt clay. Secondly, it provides important materials for the research of agricultural development. Thirdly, based on previous research on subsistence economy, the Hemudu culture is considered as a model of the earliest sophisticated agricultural society in the lower Yangtze River region.

In general, the current understanding about subsistence is a bit behind the study of material culture. If analyzing the data of subsistence remains from Hemudu Culture carefully, we will find that there are still many unsolved puzzles. As regards zooarchaeology, two parts need to be improved: the study of fish remains, and re-evaluation of the mammal remains. As described previously, the importance of fish remains has been noticed in the Hemudu report, that they are important food resources alongside mammals. Studying fish remains is restricted by the expertise of ichthyology and retrieval methods, so that detailed study in China is still rare. Nakajima and colleagues' research can be seen as an attempt to take fish bone studies further; however, since the authors are specialized in cyprinids, this research lacked broader archaeological approaches to the fish assemblage as a whole. As to the study of Hemudu subsistence based on mammalian remains, clearly the current conclusions are drawn from the hand-collected remains, and without proper quantitative analysis. It represented a significant contribution three decades ago, but some of the interpretations have not changed since they were raised despite methodological advances and new biological information on animal domestication.

Therefore, this study takes on this challenge to fill the gaps in the interpretation of the Hemudu subsistence. Both mammal remains and fish remains shall be thoroughly studied, and the results will be discussed with the integration with other subsistence elements.

Chapter 3 Review of zooarchaeological methodology for fish

This chapter reviews the research history and approaches to studying fish remains. It is divided into three parts. The first part briefly introduces the research history of the study of fish remains in China. The general research questions are listed in section two, followed by an overview of the methodological approaches in section three. The approaches include fish identification, taphonomic analysis, ageing and seasonality determination, body length reconstruction, capturing techniques, and butchering. Different methods for seasonality determination are presented.

3.1 Brief history of zooarchaeological study of fish remains

3.1.1 The development of the study of fish remains

The study of fish remains from archaeological sites started slightly later than the study of mammalian remains. The earliest study of fish remains was made in the 1840s by a Dutch zoologist, Herman Schlegel from the Rijksmuseum van Naturlijke Historie (National Museum of Natural History) in Leiden, at an early medieval town of Dorestad. According to Clason's (1986) description, 3 species of fish were identified by Schlegel, including wels catfish (*Silurus glanis*), pike (*Esox lucius*), and sturgeon (*Acipenser sturio*). This tradition was continued in Netherland in the early 20th century, when Albert Egges van Giffen, the founder of the Biological-Archaeological Institute, collected and studied the fish remains of the terpen (Clason, 1986). A few years later in Denmark, Steenstrup (1851) and Winge (1888) identified the fish

remains from Ertebølle settlement or shell mounds, but their work was rarely known by zoologists.

The French zoologist Henry Emile Sauvage's study on the fish remains from the late Palaeolithic sites in the Dordogne region of France was published in the 1870s according to Casteel's record (Casteel, 1976, P3). These 'Reindeer Age' sites contained plenty of remains of salmon and other species of fish, which were considered as the remnant of human settlement and procurement activities (Sauvage, 1875). Within a few years, Inostrantsev (1882) published Kessler's study of fish remains from the area of Lake Ladoga, which included the MNI of each species, the estimated size (both length and weight), discussion in terms of zoogeography and ancient hydrography, and an attempt to reconstruct the fishing area, and aquatic conditions during the time of occupation. This was an attempt to analyse the fish remains with ichthyologic methods, and the topics are still frequently discussed more than a century later. Kessler's methods for studying fish remains were continued and refined in the following decades in Soviet Union (Casteel, 1976, P4).

These early studies of fish remains from excavation were mainly made by zoologists, primarily focusing on the identification of specimens. At the beginning there was a lack of interpretation besides identification, but from the 1870s, the actual fish remains assemblages, and the relation between them and human beings, started to be discussed.

In Kishinouye's study (1911) on the prehistoric fish remains from shell-middens in Japan, he collected the materials by himself, rather than be given by the excavator, which is one of the earliest examples that zooarchaeologists collected their own research specimens. Kishinouye is also the first to use water-separation techniques

and microscopic analysis in the recovery and research of faunal remains.

From 1940s, more archaeologists/ichthyologists have contributed to the research of archaeological fish remains, or sub-fossil fish faunas, such as Degerbøl, Møhl, Rosenlund, Noe-Nygaard, D. E. McAllister, C. L. Hubbs, and R. R. Miller. W. I. Follett had published fish remains from many sites from 1950s to 1970s. John Fitch's work emphasized on the identification of fish species based on otolith remains.

From the 1970s, several research books were published, trying to systematically introducing the study of fish remains and standardize the research procedures, such as *Fish Remains in Archaeology and Palaeo-environmental Studies* by Casteel in 1976, *Fish Bone Measurements* by Morales and Rosenlund in 1979, *Unter-suchungen and Fisch-resten aus der frühmittelalterlichen Siedlung Haithabu* by Lepiksaar and Heinrich in 1977, *Fishes* by Wheeler and Jones in 1989, and *Introduction to Osteology of Fishes for Paleozoologists* by Lepiksaar in 1994. These books provided the knowledge of ichthy-zooarchaeology thoroughly, and have become the text books for archaeologists and zooarchaeologists. Lepiksaar was praised as 'the father of the research of subfossil fish remains' for his great contribution to the research (Clason, 1986).

On 28th of August 1981, the ICAZ Fish Remains Working Group (FRWG) was created during an informal meeting at the Zoological Museum of the University of Copenhagen, by 16 founders. In the following three decades, this international biennial meeting not only encouraged close contact among its members, but also disseminated the information presented to the best of its ability while promoting contact with other groups, organisations and individuals both within and outside ICAZ (Muniz, 1996). It also provides a platform for people from different disciplines

to communicate and cooperate. The members of FRWG are an interdisciplinary consortium of researchers, including zooarchaeologists, archaeologists, zoologists, ichthyologists, historians, and fishery biologists (ICAZ). In the latest 16th FRWG meeting held in October 2011, studies in the field of archaeology, zooarchaeology, history and molecular biology etc. were presented.

From this history we can see that the research of fish remains is becoming more and more diverse and sophisticated. Fish remains are now being widely retrieved at many sites, providing abundant material for zooarchaeological research. The theory and methodology are in development; more archaeologists and zooarchaeologists are joining this research on varied topics: retrieving strategy, taphonomy, seasonality, fishing methods, etc.. It can be predicted that fish-zooarchaeology will receive more attention in the future.

3.1.2 Study of fish remains in China

There has not been a long history of zooarchaeological research in China. Chinese archaeology has been focused on the reconstruction of ancient cultural sequences since its beginning in the 1920s, and the sequential structure was not fully set up until recently, partly because there are relatively fewer archaeologists compared to the quantity and diversity of archaeological materials.

In the 1930s, collaborated with Teilhard De Chardin, C. C. Young, a Chinese palaeontologist first analysed the mammalian remains from Anyang Yinxu, the most famous Bronze-age site in central China (Teilhard De Chardin and Young, 1929). Then archaeological work restarted in 1950s because of the interruption of the wars. Animal remains were not paid full attention until the 1980s when international

academic communication and the study of subsistence in ancient society started, and significant discoveries and achievements have been made since then. The central question has been reconstructing the sequence of domestication; therefore, fish remains have tended to be overlooked.

The first analysis on fish remains was published in 1949, about the fish bones from Anyang Yinxu, accomplished by an ichthyologist (Wu, 1949). In the following decades, basically only larger and diagnostic bones (e.g. pharyngeal) bones were collected, and recorded as a list of species in the excavation report. There are difficulties that need to be overcome: retrieval strategies; professional ichthyologic knowledge for identification and further analysis; reference collections; research topics; etc.

Fortunately, improvements have been made in the past few years. Although not completely, fish remains are generally retrieved due to the application of mesh sieving. Besides, ancient economic subsistence has drawn more attention from archaeologists, and as an important component of it, the study of fishing has begun. For example, the fish remains from Zhongba site, Chongqing region, were studied and produced evidence for the changing organization of production from the late Neolithic to the Bronze Age (Flad, 2004, Flad and Yuan, 2006).

3.2 Research questions

The research questions shifted during the history of zooarchaeological studies on fish remains. In the beginning, research was more biological rather than archaeological; but while these studies develop, varied research topics have been addressed to meet the purpose of interpreting archaeological questions e.g.

subsistence and social structure, and there are instructions on how to study fish remains systematically. The main research themes are summarized as follows.

(1) What species and bone parts of fish are presented in the faunal assemblages, and what are the proportions? It is the first step of research to identify the species and body parts, and also the necessary conditions to precede further analysis and discussion, including palaeoenvironment, fishing strategies, taphonomic processes and subsistence economy.

(2) What do the surviving and missing proportions of fish remains indicate? Compared to mammalian remains, fish bones, otoliths and scales are more likely to be affected by taphonomic factors and lost during depositional processes due to their osteo-structures. Bone absence, however, can also be an indication of the fish processing procedures. Therefore, by studying subjects like skeletal completeness, inherent properties of skeletal elements, and structural density, we may learn both environmental and processing factors.

(3) What can we learn about the subsistence economy from fish remains? Before answering this question, we need to distinguish human exploited fish remains from the naturally deposited fish remains. The human accumulated fish remains are usually kitchen waste, which are the most important assemblages for investigating human diet, food processing, and the subsistence economy.

(4) What were the fishing strategies, involving fishing tools, techniques, scheduling, and labour organization? Traditionally artefacts are examined to investigate fishing methods, including fishing hooks, net sinker, harpoons etc. However, fish remains themselves, such as the composition of species, individuals, size and age, need to be studied.

(5) What was the palaeoenvironment? Like all animals, fish can be indicators of the past environments. They are reflective to the change of many environmental and ecological factors, such as water temperature, water depth, salinity, pH value, the abundance of food resources and predators.

These are the main subjects of studying fish remains in archaeology, and they cannot be achieved without the following methodologies.

3.3 Methodologies

3.3.1 Identification

When dealing with fish remains, the first question to address is what species they represent. In order to answer this question, access to an adequate reference collection is essential, the same as with other zooarchaeological studies. A common option is the skeletal collection in a natural history museum, which may have diversity in species, and can be the only resource for the identification of rare fish. The Natural History Museums in London and Paris are famous for their abundant animal collections, and they are still the important resources of reference samples for zooarchaeologists, especially when identifying the uncommon species. Despite the abundance of reference materials, there are many restrictions for using the museum collections as the main resource of reference. Fully access to skeletal collections in museums is usually restricted. Plus, the bones are usually deliberately left articulated because they are designed for the concern of preservation and exhibition rather than identification. Consequently, a specific reference collection for the purpose of zooarchaeological research is often required.

The reference samples used in many studies are made by the zooarchaeologists

themselves following a series of procedures described by Wheeler and Jones (1989, P177-185), and finally turned into a set of disarticulated bones labelled with names. Compared with museum collections, a zooarchaeologist-made reference collection has many advantages. Primarily, it is easily accessed and can be held when doing identification since they are usually stored in archaeological laboratories. Second, it meets the professional demand for zooarchaeological research, and guarantees that relevant information such as measurements are recorded. Besides, building a reference collection is especially crucial for studying fish remains in China where museology and modern museums have only developed for a few decades and collections for zooarchaeological research are insufficient. From my own experience, finding an adequate skeletal collection in a museum, especially in China, was not an easy job, and the strict restrictions make it even more difficult.

However, each zooarchaeological reference collection has its preference, usually species-specific or site-specific. Even a grand museum cannot include all species of fish of the world. Records show that with an estimated number of 27,977, fish constitute slightly more than one half of the total number of recognized living vertebrate species (Nelson, 2006), which is almost five times of the number of mammalian species according to the statistics in 2005 (Wilson and Reeder), and this number is still growing as new species are being discovered. Besides the skeletal collection in museums, there are a few other supplementary resources which benefits fish identification.

Atlases and illustrations are easy-accessed simple-handling resources for identifying the fishes which are not included in bone labs. However, it requires extra carefulness to do identification with the sketches and photos, which may cause

confusion if someone is not familiar with the skeletal structure of fish. An atlas for identification should contain clear graphic illustrations, featuring the diagnostic areas of the specimen, and with descriptions if possible, in order to point out the characteristics which may not be shown by illustration. Johannes Lepiksaar's *Introduction to Osteology of Fishes for Paleozoologists (1994)* has been a milestone for every zooarchaeologist studying fish remains. In this book, bones are introduced orderly, and the sketches of several common fish are listed together in each chapter for morphological comparison. Although the sketches are concise, the outline and diagnostic features are highlighted. Papers relating to taxonomic study are also ideal references for identification. For example, Lu and Li (1989) introduced the characteristics of each bone of Northern Snakehead (*Channa argus*, also known as *Ophicephalus argus*) in detail, in text and graphically. Zhou and colleague's comparative study (1987) on the skeletons of two species in Channidae, Northern Snakehead and Small/Chinese Snakehead (*Channa asiatic*), provided great reference for the identification of snakeheads.

The online database is a newly developed resource serving as a reference collection, which can be easily accessed at everywhere with internet access. A comprehensive archaeological fish online resource has been built by the Department of Archaeology, The University of Nottingham: *fishbone.nottingham.ac.uk* (Figure 3.1). High-resolution photographs of modern fish bone specimens from the bone laboratory in the university are posted and can be searched for in the database. Photographs are taken from different angle of view, e.g. lateral and medial, increasing the accessibility for identification. It has an emphasis on the European fishes, such as cod, herring, salmon and trout, which have been commonly found on

archaeological sites in Europe. This database is not only built for the purpose of identification, it can also be used as an online learning resource, using the uploaded videos of the lectures from each workshop that was held in 2010 by The University of Nottingham.

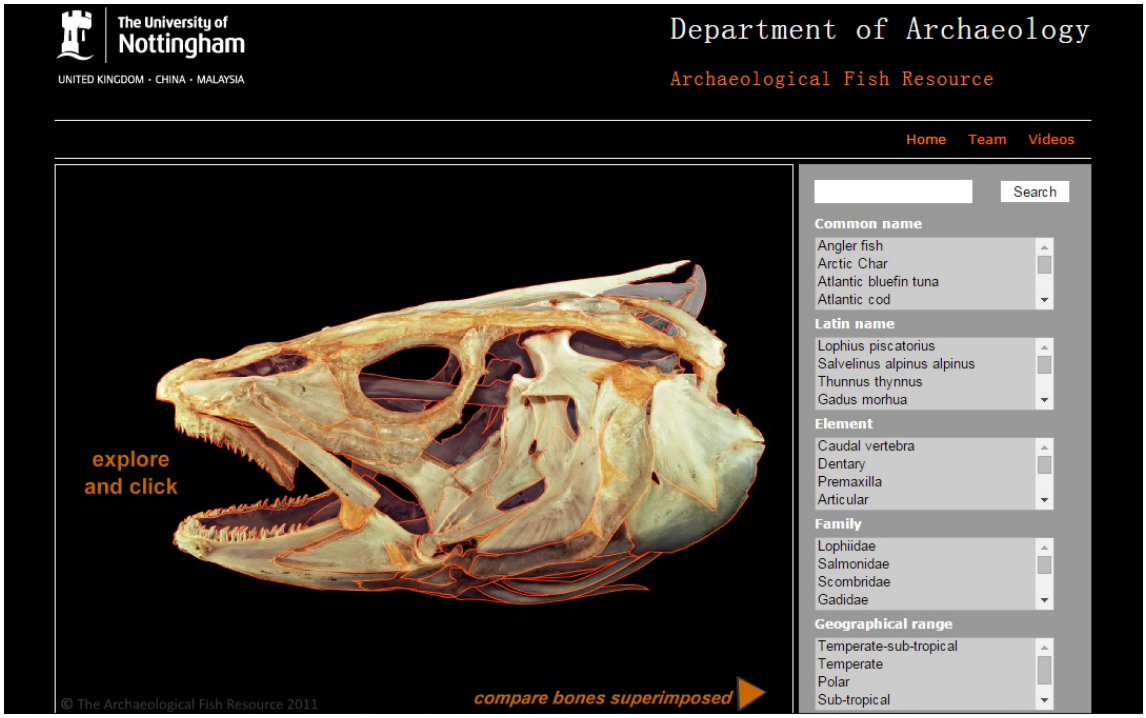


Figure 3.1 The homepage of the fish bone online database by Nottingham University.

To summarize, although there have been various resources of reference collections, some of which may have modern technology involved, the most practical and possibly accurate method is still to use a substantial reference collection. It may need much time and energy to build one, but the effort shall be rewarded.

3.3.2 Survivorship

Fish consumption does not always leave fish remains that will be uncovered by archaeologists thousands of years later. Experiments show that fish bones are less resistant to mechanical damage than mammal bones (Wheeler and Jones, 1989, P63). As was summarized by Wheeler and Jones, there are mainly two factors that

decide whether a bone, otolith or scale will survive in archaeological accumulations: the nature of the material forming the hard tissue, and the taphonomic procedures that the specimen experienced (Wheeler and Jones, 1989, P62).

First of all, not all fish will leave bones and other hard tissues at archaeological site. Taxonomically, all fish species can be classified into three categories: jawless fishes, with skeleton made of weak cartilage, cannot leave a trace in deposit except for the horny teeth on occasion; cartilaginous fishes, represented by sharks and ray, whose teeth and the calcium-rich part of the cartilaginous skeleton may survive during post-depositional process; and bony fishes, which compose the major part of fish remains.

Within bony fishes, bones do not survive equally mainly due to their structural differences between species and varied parts in the skeleton. Some species of fish have more resistant bones than others, such as the cyprinids versus the boxfishes (Ostraciontidae). On the other hand, some bones are tougher than the others within the same fish individual, such as the vertebrae are more frequently preserved rather than head bones.

When fish remains were disposed and deposited, the physical and chemical properties of the sediments turned out to be an important factor that affects the survivorship of fish bones. The ratio of survived fish bones may be reduced by sediment moving, such as reforming and fluvial processes. Wheeler and Jones (1989) suggest that fish bones are well preserved in neutral and alkaline environments but poorly in acidic deposit. Otoliths, due to their composition of calcium carbonate, hardly persist except in ‘base-rich deposits’ (Wheeler and Jones, 1989, P63).

Taphonomic processes influence the possibility of preservation from the

moment fish are captured until being studied. The first selection of fish happens during fishing, due to the application of varied fishing tools, taboos, and economic choices. As a result, the proportion of one or a few species may be emphasized while the others diminished to a small percentage or even absent, smaller fish may be discarded, showing great difference of fish species and relative proportions between an archaeological assemblage and natural population.

Further selections are made in the subsequent processing procedures. Records show that poisonous and harmful spines are usually removed firstly, as soon as fish are caught (von den Driesch, 1983). Further processes may separate head bones from trunk at the fishing site, and later deliver to the settlement for consumption and storage.

The way that fish is cooked also affects the possibility surviving. Experiment shows that boiling can make fish bones more vulnerable to mechanical damage, possibly because heating easily causes morphological change in fish bone collagen, as was shown by Richter's experiment (1986). The longer the boiling time, the more vulnerable the bones will be (Wheeler and Jones, 1989, P67), even soft enough for ingestion and digestion.

A serial of experiments have been performed to investigate the effect of digestion on fish by different animals (Jones, 1984, 1986, 1990, Wheeler and Jones, 1989, Butler, 1990, Butler and Schroeder, 1998). The experiments showed that a severe loss of bones happened after passing through the digestive system, and the survived specimens were damaged to varying degrees (Jones, 1986). Cyprinids tended to be more likely to survive after digestive process that other fishes (Butler and Schroeder, 1998). However, Butler and Schroeder (1998) also suggest that it was

difficult to separate the digestive modification that were caused by different animals, e.g. human and coyote.

The fish remains would be destroyed more after being discarded, by trampling, scavenging and activities from other agents. When fish remains are finally buried, chemical and mechanical erosion within the deposits will happen, minimizing the number of survived specimens. At last, the survivorship of fish remains will be influenced by the retrieval methods and sampling strategies, leaving us with the final collected assemblage.

3.3.3 Recovery

Studies have shown that different recovery methods highly influence the analysis of mammalian remains (Payne, 1972, Shaffer and Sanchez, 1994). Fish remains, which are rarely large enough for hand picking, require special treatment during excavation.

For detailed analysis of fish remains, sieving should be applied during excavation. However, sieving is not the only recovery method, considering the impracticality to sieve all deposits and to study them all. Therefore, sub-samples are usually taken, and sampling plans are made according to the research subjects and realistic conditions at the site.

A well designed recovery strategy can be combined with several methods, such as careful troweling, sieving, sub-sampling, etc. It is suggested that flexibility in sampling is essential because the strategy should fit the research objectives, and other practical issues e.g. time and budget (Wheeler and Jones, 1989, P38). Therefore, each site should have a unique retrieval strategy, depending on the

research questions, the abundance of fish remains, and cultural background and other information about the site.

3.3.4 Ageing and seasonality determination

In this section, the methods for ageing and seasonality determination will be discussed together due to their continuity and inseparability in research. The studies of both ageing and kill-off seasons of fish share the same ichthyological basis; therefore a general introduction of biological background of fishes' growth will be addressed before coming to zooarchaeological methodology.

3.3.4.1 The growth of fish

Fishes grow following a special pattern, which can be summarized as continuity and periodicity. Unlike higher animals such as mammals and birds, fishes grow continuously throughout their lives, although the increment rate gradually slow down as fish grows older (indicated by the data in Figure 3.5). Taking the common carp (*Cyprinus capio*) for example, its common length is 31 cm (Chugunova and National Science Foundation (U.S.), 1963), but the reported max length is up to 110 cm (Kottelat and Freyhof, 2007) and the oldest individual which has been reported is 38 years old (Hinton, 1962). From my interview with the fishermen near Tianluoshan I have noticed that an experienced fisherman usually tells the age of fish simply by their size. This simple but practical method has also been applied in zooarchaeological studies, which will be presented later.

As fish grows larger, calcium gradually deposits at the margin of hard tissues so that they expands outwards, leaving traces, usually in the form of concentric circles, known as the growth rings or circuli, on them. Among all the hard tissue parts,

scales, otoliths, fin spines, opercula, and vertebrae are frequently used for investigating age and growth of fish in fishery and zooarchaeological studies.

Growth rings are formed by the regular fast-slow intervals of growth rate: each ring represent a small unit of fast-slow growth cycle; a group of close-set rings represent a period of slow growth, while widen-set rings are formed during rapid growing time, and together they form a growth cycle. The growth rings on skeletal parts are formed annually; however, daily increments have been detected on otoliths (Pannella, 1971, Pannella, 1980, Barkman and Bengtson, 1987, Van Neer et al., 1993), probably related to the 24-hour light-dark photoperiod, which entrains an internal, diurnal clock. It is an effective method to determine the age of fish larvae.

The growth rate of fish is greatly dependent on a variety of interacting environmental factors, including water temperature, levels of dissolved oxygen and ammonia, salinity, and photoperiod. Among all the environmental factors, temperature has the strongest influence on the growth of fish (Moyle and Cech, 2004). Fisheries research revealed increased food consumption, metabolism and growth rate with warmer temperature and opposite results with lower temperature in the sustainable range (Wurtsbaugh and Cech Jr, 1983, Moyle and Cech, 2004, P128). Besides, the other factors listed above are also more or less affected by temperature such as the solubility of oxygen and ammonia, along with the abundance of food resources of fish. As a result, in temperate and near-polar waters where water temperature and day-length change annually, the growth cycle of fish is also annual and leaves regular distributed growth rings on hard tissues accordingly (see Figure 3.2). Since there is no distinct seasonal or annual change of temperature in tropical waters, the growth rings are more related to reproductive activities, and

environmental events such as water current and lunar cycle (Pannella 1974).

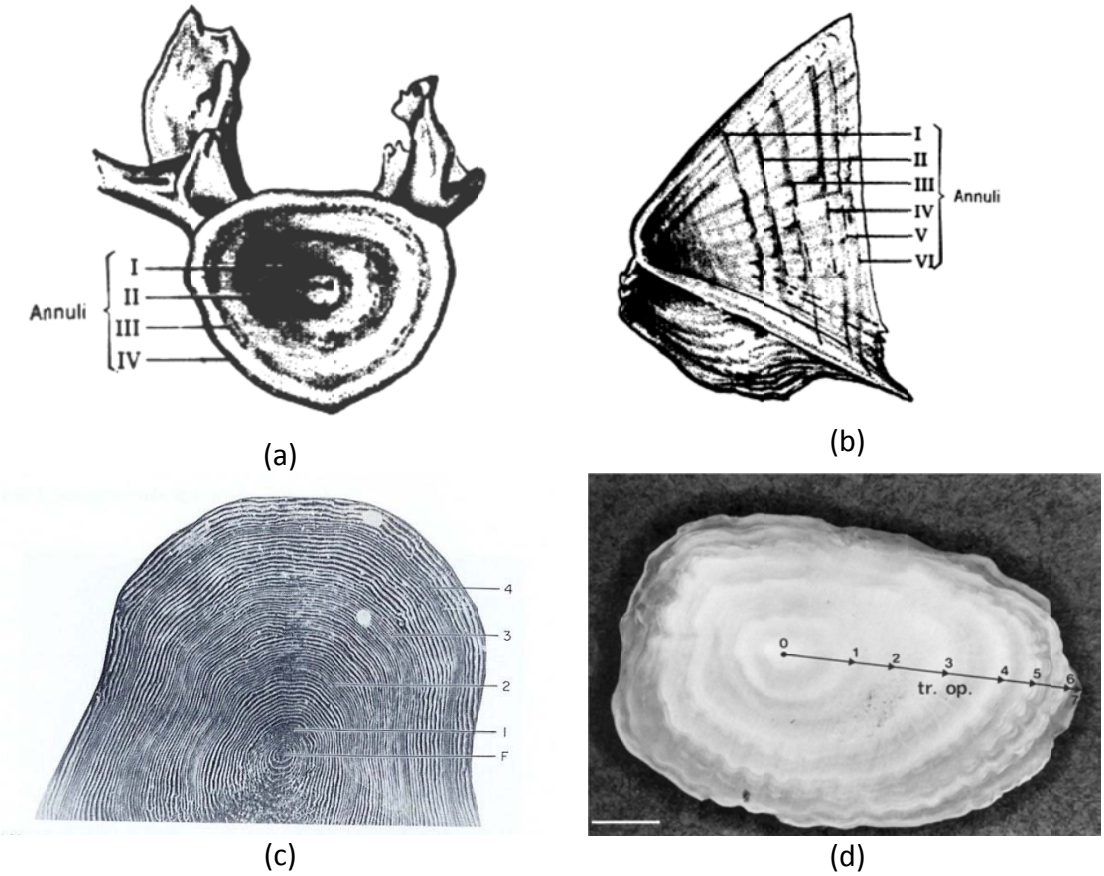


Figure 3.2 Annual growth marks (annuli) on (a) vertebra of a catfish (*Noturus*); (b) operculum of a perch (*Perca*) (Lagler et al., 1977, Fig. 5.11); (c) scale of a mature sockeye salmon (*Oncorhynchus nerka*) (Royce, 1972, Fig. 4.23); (d) left plaice otolith under reflected light, lateral view (Van Neer et al., 1999, Figure 2), labelled by the numbers. 'F' in (c) and '0' in (d) represent the centre of nucleus on scale and otolith.

Although environmental factors strongly affect the absolute growth rate of fish, age and maturity have the most marked effects on the relative growth rates (Wheeler and Jones, 1989, Moyle and Cech, 2004, P132). When fish become sexually mature, increasing amounts of energy and minerals (especially calcium) are diverted to growth of gonadal tissues, causing an interruption in the regular cycle of growth. The reproductive events are mostly reflected on scales, possibly because the deposition of minerals in scales is more sensitive to physiological change, but also on other hard tissues in some species, for example, linear spawning breaks can be

observed on the otoliths of surgeon fish (*Acanthurus chirurgus*) with scanning electron microscope (Pannella, 1980, P541, Plate Ⅶ).

3.3.4.2 The methods

The cyclical and continuous growing progress of fish indicates that it provides a good possibility to make a subjective assessment of age and the season at which the fish was killed from the hard tissues. For years zooarchaeologists have been examining and applying different methods with fish remains from various ages and places. These methods are originally rooted in ichthyologys, but distinctively developed to adapt to zooarchaeological materials and purposes. First of all, the archaeological fish remains, which are usually fragmentary, weathered and full of uncertainty, are obviously more challenging for investigation comparing to modern samples, and require interdisciplinary knowledge e.g. taphonomy. Besides, innovative methods have been developed in order to answer the archaeological questions which are independent of ichthyology, and seasonality determination is one of them because it is a known factor in modern samples.

Ageing and seasonality determination have always been one of the key research subjects in zooarchaeology. Three frequently used methods are summarized as follows.

Method 1

The methods for age and seasonality determination is developed on account of the annuli (growth rings) on the hard structures, including otoliths, opercula, vertebrae, and pectoral fin, which reflect the seasonal. It works by comparing the

outermost annulus on archaeological specimens with reference samples which show the sequence of annuli growth. Scales, although bearing clear growth rings, are more important for fisheries studies rather than zooarchaeology, for their poor resistance to taphonomic processes.

The study of growth rings on skeletal parts of fish requires abundant modern samples for referencing like other zooarchaeological methodology studies. In the case study of Praestelyngen, Denmark, Noe-Nygaard (1983) fully studied the incremental growth rings on vertebrae of 100 modern pike which were captured at known dates throughout one year, and came to the conclusion that the fish-killing events occurred mostly in summer. Van Neer has examined the modern increment widths on the otoliths of 387 plaice, a sub-sample which were taken from a large sample database containing 4595 modern plaice, to create a reference dataset for studying the archaeological materials from Raversijde, a 15th century fishermen's village on the Belgian coast (van Neer et al., 2004).

Both case studies have shown the importance of a large reference collection in the research of seasonality. Both of them also pointed out that the samples were retrieved from different months of the year, so that the growth ring patterns show variations between seasons. Unfortunately there is usually no ready sample which meets archaeo-ichthyologists' standard, therefore, catching and preparing the reference sample has become part of the seasonality study. Because the study of fish is usually species and geographical specialized, a gigantic reference collection of varied species is required when studying different species of fish, indicating a time and effort consuming job.

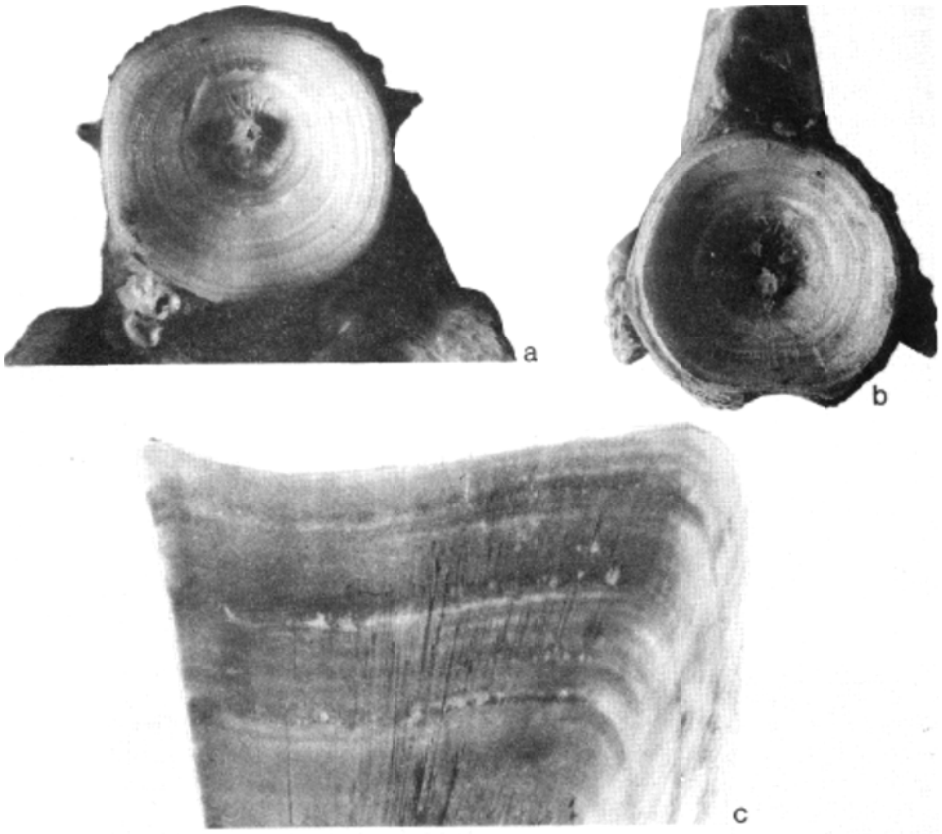


Figure 3.3 The growth rings on different skeletal parts of a 76 cm long pike caught in October, featuring the outermost layers which are almost completed. (a) A basioccipital; (b) a precaudal vertebra; and (c) an epihyale. The pictures are taken from Noe-Nygaard (1983).

Secondly, it is also crucial to choose the proper part(s). Research has shown that the time of annulus deposition is not identical in all body elements, with bone lagging 1.5 months behind otoliths (Yasuda, 1940). The accuracy of seasonality estimation with bone are considered to be between ±2 months (Casteel, 1976) and ±3 months (Voorhies, 1969).

Scales and otoliths are generally preferred in fishery studies because both parts are more sensitive to the change of environmental factors and health conditions. Besides, daily increments on otoliths can be examined under electron scanning microscope so that detailed discussion on age profiles of populations and growth rates are available. Skeletal part such as opercula, epihyale and vertebrae are also

used depending on the researching subject.

However in the archaeological circumstances, there are not as many choices as in fisheries studies after thousands years of decomposition. Scales are barely preserved at archaeological sites, except in extreme conditions such as water-logged environment; otoliths cannot survive in acid sediments due to the compositional aragonite which are less stable than hydroxyl-apatite of bone (Carlson, 1988); flat bones such as opercula may be crushed, especially at the edge which is crucial for season determination; vertebrae are relatively robust and possibly are the most skeletal parts from archaeological sites comparing to the others, but less diagnostic to species. Considering the factors of readable growth rings and preservation possibilities, otoliths, vertebrae and opercula are the better choices for seasonality study.

Otoliths, or 'ear-stones', are small concretions of calcium salts which are located within the inner ear of bony fishes (Casteel, 1976, Pannella, 1980, Wheeler and Jones, 1989). There are three otoliths on each side of head cavities, the sagitta, the lapillus and the asteriscus, setting at right angle to one another. Sagitta has been more intensely studied than the other two, for that it is the largest of the three otoliths in most bony fishes, except for the Ostariophysi which have larger asteriscus. It should be taken in mind that in many literatures the term 'otolith' actually refers to 'sagitta'.

The growth rings on otoliths are usually able to be observed under microscope with reflected light (e.g. Figure 3.1-d); sometimes it may require thin-section and polishing when the otoliths are too thick to see through. Generally the interval opaque and transparent bands in annuli satisfy the normal researching objectives

during season determination. In some cases, daily increment layers are studied in order to pursue detailed information (Van Neer et al., 1993). On the other hand, since the deposition of calcium on otoliths is sensitive to internal and external changes, the results may be confused by interruptions.

In contrast, the calcium deposition on skeletal parts is slower, but more stable. Due to this advantage, many ichthyologic studies choose vertebrae over otoliths for constructing age profiles. In the case study of ageing and growth of the Tibetan catfish (*Glyptosternum maculatum*) in the Brahmaputra River, China, Li and Xie (2008) pointed out that the otoliths of Tibetan catfish are irregularly shaped and relatively small, while the vertebrae have clear-cut growth rings which are more suited for age profiling. Vertebrae are more commonly used in zooarchaeological studies, such as on the fish remains from Praestelyngen (Noe-Nygaard, 1983) and Raversijde (Van Neer et al., 1999).

Beside of otoliths and vertebrae, skeletal elements such opercula, epihyale and pectoral spine (especially for catfish) are also used for seasonality determination (Noe-Nygaard, 1983).

Based on the increment of growth ring, the method is relatively accurate and the results are repeatable as long as the reference samples are properly prepared. However, it is restricted by a few issues. The most common issue is the preservation condition. The outermost growth ring, which is the key part for the estimation of seasonality, can be easily worn by weathering and post-depositional processes, causing difficulties for precise reading. Besides, the reading accuracy is also related to the property of the specimens themselves. It has been proved that the growth rings are less legible on older individuals. For instance, comparative studies on ageing of

Tibetan catfish revealed that the numbers of visual growth rings on articulation surface tends to be less than those on the sectioned surface, especially for the individuals which are over 10 years old (Ding et al., 2011).

Method 2

The general idea of this method is to deduce the age of fish from the results of size reconstruction. Since fish grow continuously and regularly, they usually reach a certain length around the same time of their lives, and this can be used as the evidence to estimate the age and capture season of fish.

There are only a few studies in which fishing season are estimated using this method, represented by Nakajima and colleague's research on fishing subsistence at Neolithic sites in Western Japan and Lower Yangtze River of China (Nakajima et al., 2010b, 2011, 2012). The body lengths of the archaeological remains were first estimated using reference samples, and then compared with the length data of modern samples, to estimate the age of fish and at which season the fish were captured. The results at Irie-naiko (Jomon period) and Asahi (Yayoi period) showed narrow distributional range (Figure 3.4), indicating seasonal fishing events. When size reconstruction is commonly applied in zooarchaeological studies, the estimation of age and seasonality by size is simply a by-product. Similar estimations are actually used everywhere, by ichthyologists and fishermen.

However, the practice is less accurate than the theoretical modal. It is known that the increment of length is influenced by many complex factors, climatic, environmental, difference between breeds, etc., so the error between archaeological specimens and reference samples is inevitable. On the other hand, since the

increment rate slows down as fish grow older, the size difference between individuals that are caught at contiguous seasons may be minor, and the accuracy of results may diminish accordingly (Figure 3.5).

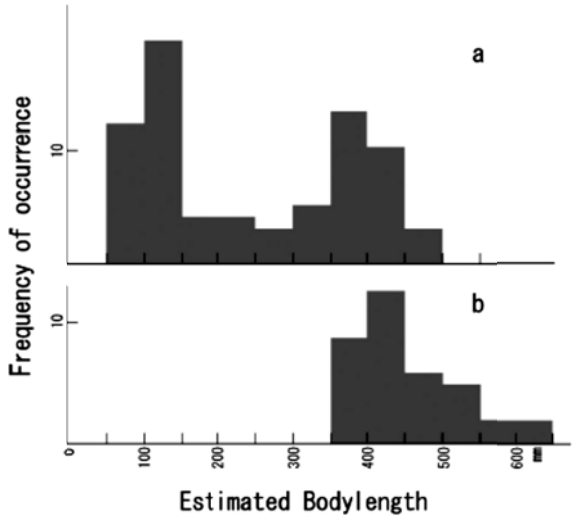


Figure 3.4 The body length distribution patterns of common carp from: a) Asahi in Yayoi Period, the first peak represents fish that were caught in the autumn harvest, and the second represents the spawning-season fishing event; b) Irie-naiko in Jomon Period, where only the spawning-season fishing is observed.

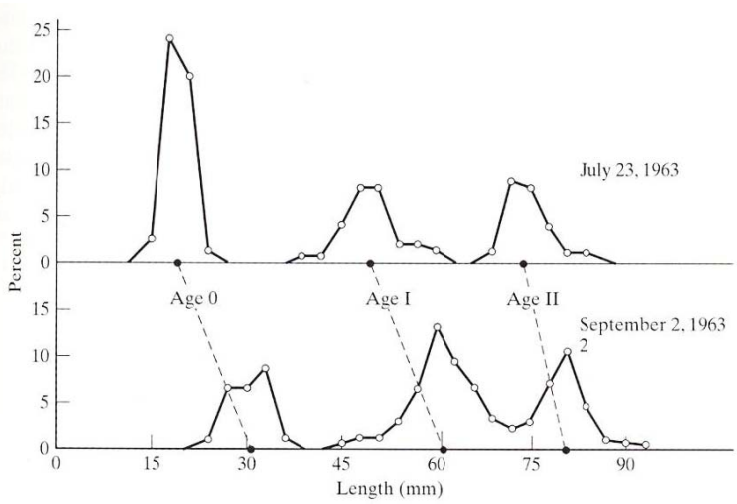


Figure 3.5 Length frequency distribution (percentage) of pond smelt (*Hypomesus olidus*) from Black Lake, Alaska, in July and September (Royce, 1972, P154). From graph we can see that the individual peaks of the population separate by age classes. Increased negative slope of dashed lines indicate that growth increment slows down from approximately 29 mm to 24 mm per year (calculated from the mean length between age classes) as age increases.

Method 3

In addition to the analysis of fish remains, the knowledge of modern fish can be the indication of the seasonality. Same as their growth pattern, fish living in temperate and cold zones usually perform seasonal behaviours, such as migration, spawning, and torpor (hibernation), triggered by the change of temperature, salinity, and other environmental factors. Ethnological and modern fishery studies can provide reference data for the determination of seasonality at archaeological sites.

Ichthyologic research present that a majority of fish migrate for the purpose of reproduction, allowing eggs to be laid in the adequate environment, and the hatchlings of different life-history stages are separated by habitat, to reduce the likelihood of intraspecific completion and cannibalism and thus maximize the survivorship of larvae (Moyle and Cech, 2004, P189). The representative migratory fish include salmon, tuna and eels, which may travel thousands of kilometres to the spawning streams in a short period. Some fish migrate in response to changing environmental conditions and food resources, for example, herring (*Clupea harengus*) in the North Sea migrate during spring to chase the plankton that was brought by the inflowing warm Atlantic waters. Spawning may be the greatest event for a fish, for it requires quite a large amount of energetic investment to grow reproductive organs, and for some species to migrate as well. Spawning usually occurs at a fixed time each year for a species, although it may vary due to the fluctuation of temperature. Not only the migratory fish, resident fish also move to the adequate areas to breed, and sometimes nurse the hatchlings for a certain period. A few lake-dwelling fishes, e.g. common carp, crucian carp, snakehead, etc., move to the shallow and grassy areas at the edge of the water bodies to spawn. Fish

may perform special behaviours during breeding seasons, such as courtship, schooling and parenting, which inspire the development of special fishing techniques may be developed. There are diverse ways for fish to survive winter. Many freshwater fish go dormant, lowering metabolism and sinking at the bottom of water or diving into mud, due to the drop of temperature.

Fishes undergoing these events are normally vulnerable, and they can be captured with relatively simple fishing methods. Migratory fish such as tuna (*Thunnus thynnus*) and swordfish (*Xiphias gladius*) usually swim into shallow waters inshore during migration, where fishermen use nets and harpoons to catch them. Salmons are well-known for their spawning migration from seas ascending rivers to approach the spawning beds. It usually turns out to be a dangerous journey, during which they are exposed to predators including human beings. In Alaska, weirs and traps are set in streams and tidal areas to catch the migratory salmons, shown by both ethnographical and archaeological evidences (Krause, 1956, Moss et al., 1990, Stewart, 1977).

The unordinary behaviours during spawning season, for example migration, are possibly the weaknesses of fish. The resident fish, such as some cyprinids (e.g. common carp, crucian carp, grass carp, etc.), perform local migration in a small range to the spawning beds, which are usually grassy areas in shallow water. Although with the shelter of grass, the spawning fish may be ambushed by the predators or trapped in fishing gear. Burbot and pike spawn just beneath the ice in shallow water in the early spring. Fishermen in northeast Europe and North America usually beat the ice heavily with clubs or mallets, and the vibration will stupefy the fish for a short time, allowing the fishermen to retrieve the fish from under the ice. Some fish species

exhibit parental care and become more aggressive during the spawning and hatching seasons, such as catfish and snakeheads. Under this circumstance, the parent fish are easily provoked with simple baits and traps (Lan, 1958).

The fish in hibernation are so inactive that they can hardly resist attacks. In winter, the inactive eels usually gather around entrances to lakes, rivers and streams, or in deep holes close to tidal entrances to freshwater or estuaries (Lane, 1978). Because of this habit of eels, fishermen in northern Europe usually catch the hibernating eels by breaking a hole in the ice and spearing circularly (Gabriel et al., 2005, P57). In Cambodia, the first fishing season occur when fish come out of the refuge at the beginning of wet season; while in cool seasons, farmers exploit the instinct of hibernation and dig deep-water ponds to attract fish which are looking for refuge waters, for the later household consumption (Nesbitt, 1997, P100-102).

In conclusion, seasonality can be inferred from the ecology of modern fishes (Wheeler and Jones, 1989, P159). It has advantages especially for fish remains which are not preserved well enough for conventional seasonality estimation methods. Seasonal fishing of migratory and spawning fish may present large assemblages of fish remains of certain ages or sizes. In the case of anadromous salmonids, most of which were caught in rivers during migration (Matsui, 1996), there could be a large group of fish at the same age (genus *Oncoryrichus*, single breeding in life), or a regular distribution of different ages (genus *Salmo*, several breedings during life).

In archaeological studies, the methods for seasonality determination are possibly not used singly. Some methods may be used as calibration in order to establish the reliability of analysis.

3.3.5 Size reconstruction

Calcium gradually deposits on the outer side of bone structures, making them enlarge continuously. This leads to a common phenomenon: among the same species, larger fish tend to have larger bones, and vice versa, i.e. the size of fish is positively correlated to the size of bones.

Two criteria of size are commonly used in this part of study: length and weight, each of which has several ways to be recorded in the discipline of ichthyology. Length can be recorded as total length, standard length, and fork length (cannot be measured on some species of fish, e.g. snakehead), while weight can be recorded as total weight and gutted weight. Between these two categories of measurements, the size of fish bones are more related to the length of fish rather than weight, for instance, fish wish same length may weigh differently. In contrast, weight of fish is more difficult to estimate, because unlike length, weight is a three-dimensional factor, and neither size nor weight of fish bones is directly related to the original weight of fish, especially after long-termed post-depositional processes the weight of bones may change. Considering all the reasons above, reconstruction of length is more often used rather than weight.

There are two fundamental principles to reconstruct the size of fish: choose the adequate skeletal parts (or otoliths) for taking measurements, and prepare the comparative specimens. In Wheeler and Jones' book (1989), three overriding qualifications in selecting bones for size estimation are addressed:

1. Correct identification of both the bone and the species should be possible;

2. The bones should be solid structures with clear-cut features which allow accurate and reproducible measurement, because a small error on the measurement

will be multiplied on the estimation of body size;

3. Measurements should be taken on the points that receive least damage in deposits or during recovery, in order to obtain the maximum number of certainly reproducible accurate measurements.

The following bones are suggested to choose for further measurements according to these principles: premaxilla, dentary, articular, quadrate, basioccipital, parasphenoid and abdominal vertebrae. Thin-edged bones such as opercula and bones without well-defined measuring points such as maxilla are less recommended. However, there is no fixed regulation on which bones must be chosen and which must not. The choice should be made based on the condition of the materials, and accordingly the bones and measuring points may vary from site to site.

Many methods have been developed for the purpose of estimating the size of fish. Casteel (1976) summarized and compared five major methods that have been employed in zooarchaeological research, and came to the conclusion that the single regression method is the best for its simplicity and accuracy at the same time, which is agreed and applied by many zooarchaeologists (e.g. Wheeler and Jones, 1989, Zohar et al., 1997). Not only zooarchaeologists, fishery biologists need reconstructed size to investigate the diet of fishes and the ecosystem, by examining fish's stomach content, identify and estimate the size of prey fish from their remains (Mann and Beaumont, 1980, Fickling and Lee, 1981, Radke et al., 2000).

The single regression method necessitates the gathering of a large reference collection that includes individuals of a range of size and of each species. The sample capacity needs to be decided to adapt varied research topics. If only roughly

estimation is required, a few samples may meet the demand; when estimated size is for further analysis, more specimens should be collected. With the measurements of fish length and the chosen bone or otoliths, single regression equation or distributional graph can be derived, and subsequently used as an intermediate criterion to calculate the original size from archaeological samples.

3.3.6 Capturing

Fishing hooks, net sinkers harpoons and stone walls are probably the commonest fishing tools that have been discovered from archaeological sites, yet they may only represent a small proportion of all fish capturing methods that were used at the site, for that many of them do not leave archaeological evidences.

After summing up the fishing methods and gears of the world, Gabriel and colleagues (2005) pointed out that only a small number of basic techniques were involved in these methods. They can be categorized as: (a) wounding gear, such as spears and harpoons; (b) lines and hooks, including handlines and longlines; (c) traps, including pots, fyke nets, weirs and pound nets; (d) nets, which according to different methods of operation can be grouped into gillnets, trammelnets, liftnets, trawls, seine nets and surrounding nets. Many fishing gears in this list are made of wood and fibres, which hardly preserved except in special conditions e.g. waterlogged. Although there may not be direct evidence of fishing tools, they can be deduced through indirect methods.

Table 3.1 Selectivity of some fishing methods, summarized from Gabriel et al 2005 and Colley 1987.

Fishing method	**Gear**	**Species range**	**Size range**
Gathering	Usually by hand; sometimes with auxiliary gear of general nature	Selective	All sizes, selective by exact method.
Poisoning	Poison	Wide	All sizes
Animal fishing	Cormorant, otter, sucker fish etc.	Selective	All sizes, selective by exact method.
Spearing	Spears, harpoons, etc.	Wide	Large
Line fishing	Hooks	Selective	Selective
Gill netting	Gill net	Selective	Small
Drum trapping	Drum trap	Selective	Small
Tidal trapping	Trap	Wide	All sizes
Seine netting	Seine net	Wide	Large
Cover pots & cast nets	Cover pots/nets, cast nets, sinker, etc.	Selective	Large

Each fishing gear and method usually applies to certain targets which are classified by various criteria, such as behaviour (e.g. nocturnal and migrating fish), habitat (e.g. deep/shallow water fish), or simply size, causing selectivity (see Table 3.1 and Figure 3.6. Lagler, 1978, Colley, 1987, Rollefsen, 1953, Millar, 1995). Therefore, it is possible to discuss the fishing strategies by analysing the species

composition of fish remains, mortality profiles and the size of fish. A simple example is that catastrophic mortality profile possibly implies fish poisoning. In Balme's (1983) study on the fish remains from four sites along the Darling River in western New South Wales, she was able to distinguish gill net and drum trap fishing by their distributional patterns of fish length (Figure 3.6 - b).

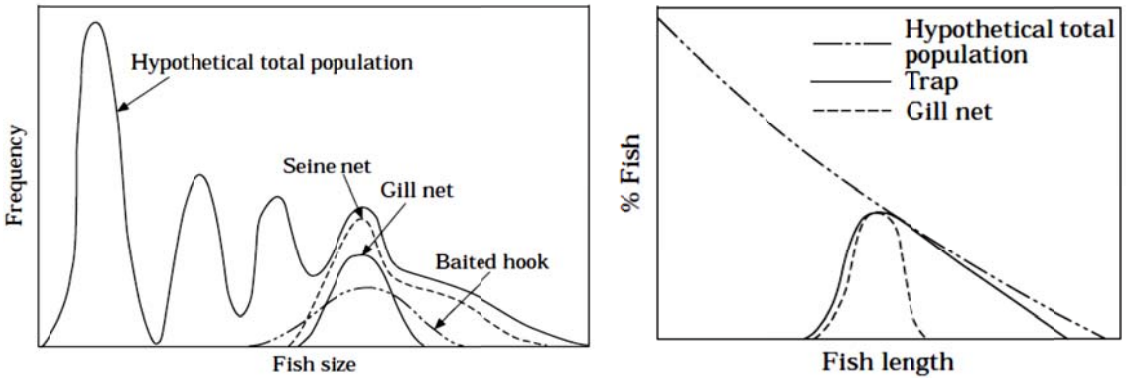


Figure 3.6 Fishing gear selectivity model (a) for gill net, hook, line and seine net (Hamley, 1975); (b) for drum trap and gill net (Balme, 1983).

Ethnographic records are important resources for archaeological research when direct evidence of fishing techniques is absent, and also the reference data to reveal how the uncovered fishing artefacts worked. Although large mechanical fishing gears are generally applied in modern fishing industry, primitive but efficient fishing methods and gears are still in use in many areas, such as the southeast Asia, Alaska, and Aboriginal Australia (Fernando, 1993, Baird et al., 1999). In China they are mostly found in the countryside and the regions where minority nationalities inhabit. Literal records about primitive fishing in these areas can also be found (Lawrence, 1969, Heinzer and Elsasser, 1980, Luo, 1996). Many of the fishing gears are surprisingly simple, such as scoop nets, drop pots, and sometimes collecting with bare hands after drying the ponds, showing fishermen's thorough knowledge about fish and

their rich experience.

In conclusion, interpreting fishing strategy at archaeological sites requires a sophisticated knowledge of fish behaviour and habitat, according to which the specific fishing gears were chosen and the fishing strategy was applied. When there is not enough direct evidence of fishing gears, the deduction of fishing methods can be made according to the analysis of fish remains, sometimes with the assist of ethnographic records. Fish remains show the selectivity of the fishing methods, which may be distinctively different from each other, either by species or by size. Additionally, ethnographic records provide live examples for the interpretation of archaeological samples.

3.3.7 Butchering

Butchering marks on mammal remains have been commonly observed and studied, while the frequency of such marks on fish bones is much lower (Lyman, 1994, P439). The scarcity of butchering marks on fish bones may be attributed to several factors.

Butchering practice does not always leave marks on bones, due to the processing methods and tools that were used. In some cases, blades are barely involved during processing. Nakajima (2006, Figure 7) introduced a method to process crucian carp for consumption that might have been used during Jomon Period in western Japan. The major steps of gutting and decapitation in this method are finished with bare hands, and blade is only used to cut the isthmus between gill chambers in order to remove the branchial artery and drain the blood, leaving quite few cutting marks. On the other hand, butchering marks are intentionally avoid

because the contact with bone blunts the blade (Wheeler and Jones, 1989, P65).

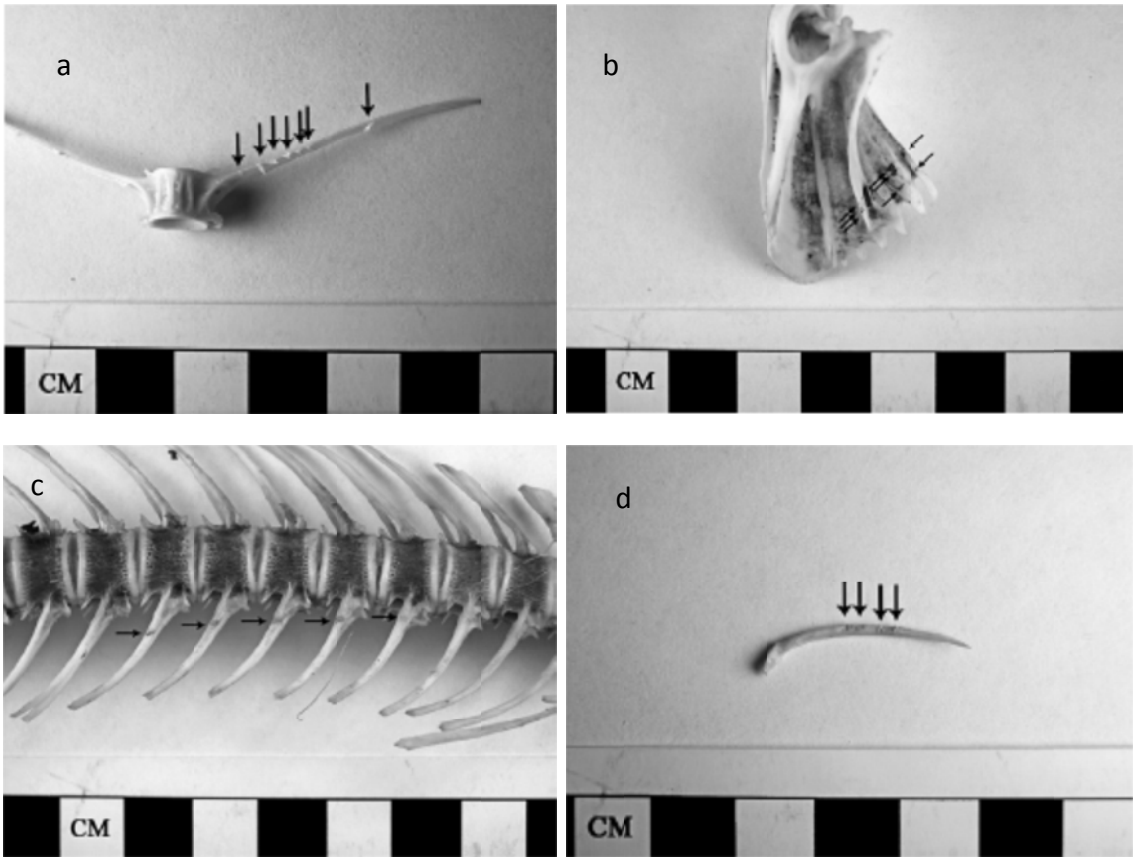


Figure 3.7 The butchering cut marks on a) a caudal vertebra, b) a cleithrum, c) a series of cut marks from a stroke, and d) a rib, from the experiment by Willis and colleagues (2008).

Same as those on mammalian remains, butchering marks are restricted to a small number of fish bone for each species, such as the filleting marks on and the decapitation marks on the first few vertebrae, although the distributional locations may vary between fish species and sites due to different butchering techniques. Willis and colleagues (2008) suggested that in contrast to archaeological records, cut marks frequently appear on fish bones during their experiments of fish butchering, but concentrated on undiagnostic bones, including vertebral neural and haemal spines, vertebral transverse processes, pterygiophores, and ribs . Besides, these cut marks intensive parts are relatively fragile, and therefore butchering marks could

easily be obscured or destroyed by taphonomic processes such as root etching and trampling, causing the dearth of butchering marks.

3.4 Summary

Fish remains, normally found as skeletal parts, otoliths and scales, are less resistant to taphonomic processes, and difficult to be fully retrieved due to their average small size and fragility.

Studying of fish remains requires professional knowledge of ichthyology, a sound collection of reference samples, well-planned recovery strategies, and most important zooarchaeological perspectives. It shows the interaction of human and the aqua environment represented by fish remains, the many uses of fish, and even social organization such as during the annual fishing events of migrating fish.

The studying methods of fish remains slightly differ from that of mammals and birds, mostly for the reason that fish keep growing through the life unlike the animals of higher classes. Methods for the estimation of fish size, age and kill-off seasons have been developed according to rules in ichthyology, but modified to adapt zooarchaeological subjects. Taphonomic studies are crucial for analysing fish remains. Each procedure of the taphonomic processes may have played strong influence on the remains, including butchering, cooking, digestion, deserting, weathering, and else post-depositional actions. Generally these methods require the assistance of great deal of reference specimens.

However, fish assemblages have been under-exploited in the past decades. In China, where archaeology is developing fast, fish remains have been overlooked even

in the sites where fish possibly have played a major part in the subsistence economy. The study on fish assemblage from Tianluoshan will be the first attempt to systematic research on fish remains in China.

Chapter 4 Materials and approaches of faunal analysis used in the current study

This chapter aims to present the methods adapted for the study of Tianluoshan faunal assemblages, sequentially, from sample recovery to data processing. Considering that fish and mammalian remains were retrieved and processed differently from the beginning, the methods for studying these two assemblages will be stated separately.

For fish remains, the methods are applied to address the following objectives:

1) Taphonomic effects of retrieving and processing on fish remains. Sub-sampling strategy and quantitative method have been carefully designed to adjust the bias to a tolerant range for data processing.
2) Taxonomic composition and relative importance. A reference collection containing a few species was built at site for the identification of fish species and elements.
3) Body length reconstruction of the predominant fish. The methods are selected from those summarized in the previous chapter, and adjusted for the conditions of the study samples. Abundant metric data of both archaeological and modern specimens have been taken for this objective.
4) Seasonality assessment. The methods for seasonality estimation from the fish remains are also summarized in the previous chapter. Modern specimens are collected as a reference for this topic.

For mammalian remains, the following issues are raised:

1) Species and relative importance.

2) Age profiles of pigs and deer will be established. It will help to assess whether the pigs from Tianluoshan were wild or domesticated, and to investigate the deer hunting strategies at Tianluoshan.
3) Body part representation and locational distributions.
4) Morphometrics. These will assist the assessment of domestic or wild pig at Tianluoshan.

4.1 Materials

The study materials for this thesis include all mammalian and fish remains that were recovered in the previous four seasons of excavation at Tianluoshan. The bird and reptile remains were briefly studied in my MA dissertation (see Chapter 8), but the numbers were not great enough to include within analysis. Most bird and reptile remains were collected in the excavation seasons thereafter.

These remains are mainly retrieved from the stratigraphic layers at the site, including layer 3 to 8 in the central excavation area and layer 7 in DK3, which is also the earliest at Tianluoshan. As stated in Chapter 2.3.3, reptiles and birds are temporarily excluded in this research due to the lack of relevant reference collections, and will be studied in future projects.

In addition, sub-samples for the quantification of fish remains were taken from the excavated residue in 2011 and 2012. Restricted by the excavation schedule, samples could only be taken from the lower layers of the trenches at the edge of the excavation area.

4.2 Recovery and sampling strategy

The recovery strategies used at Tianluoshan have shifted over the excavation seasons, from rough to well-planned. In the first season in 2004, all animal remains were hand collected and there was no wet-sieving practiced. Therefore, there were

only larger and easy-identified bones of large sized animals, such as articulations, vertebrae and tortoise shells. Wet-sieving was introduced into the excavation since 2006 the second season.

In the second season of excavation, all the deposits from each context were retrieved and sieved, and a large assemblage of fish remains was collected and separated from mammalian remains on site. In addition, systematic sampling was applied for archaeobotanical research which produced wet sieved (residue) samples. Each trench was divided into 50 1m×1m squares, and 5 2L samples were taken from each layer. This sampling method continued in the third and fourth excavation seasons (2007 and 2008).

4.2.1 Fish remains recovery

A few large fish bones (Figure 4.1–a) were hand-picked during excavation in the first season; apart from those, fish remains were hand-collected from the wet-sieving residues. The procedure is described as follows. First, all deposits from each context were sieved through two different sized meshes: a coarse 4.5 mm mesh and a fine 2.8 mm mesh. Second, the heavy residues from two sized sievings were saved seperately, and small remains such as bones, small lithics, and seeds were picked out from them. Therefore, in each context, there were two groups of fish remains, one from coarse sieving, and the other one from fine sieving, both stored separately (Figure 4.1-b, c). At last, the number of each group of fish bones was counted by the excavator, so the total number of the fish remains was already known before my project started.

The collected fish remains were biased due to the flaw of this retrieval stratedy. First, the fish remains from stratigraphic layers mainly consist of vertebra,

basioccipital, pharyngeal bones, and teeth, but head bones and girdle bones were contained from my sieving samples (see Chapter 5, section 5.2), indicating the specimens were biased during retrieval procedures. The reason is that retrieving was performed by unprofessionals, who were capable of collecting most fish vertebrae and pharyngeal bones which had a clear-cut look, but not fragmented head and girdle bones which looked like wood splinters after deposition. Fortunately, the content of bone rich pits was all saved, providing materials for analysing body part distribution. Second, a few processes had been undertaken before I gained access to the assemblage, making it more complicated to subsample, record, and quantify. Each coarse and fine sieved sample had been sorted into pharyngeal teeth and vertebrae. Some basioccipitals were mixed in the vertebrae samples, and some were further sorted into 'special-shaped vertebrae' due to their unusual cone shape (Table 4.1). Therefore, sampling and quantification were carefully designed in order to adjust the bias (Section 4.2.2. and 4.7 in this chapter).

(a) (b) (c)

Figure 4.1 Three groups of fish remains from Tianluoshan. (a) hand-picked vertebra; (b) coarse sieved specimens; and (c) fine sieved specimens.

4.2.2 Sub-sampling strategy for fish remains

During the analysis of fish remains, sub-samples were used as the basic unit for sorting, recording, identification and quantification. They were taken from the retrieved samples by context, usually one from coarse sieved sample and one from

fine sieved sample, each containing 300 to 400 specimens. This number had proved to be an adequate sample size for both quantitative analysis and handling the Tianluoshan project after taking a few trials. Details were particularly taken care of during sampling procedure, in order to make sure that the sub-samples were not biased: fish bones were first gently mixed in a tray to avoid the layer effect that smaller bones tend to sink in the lower layer in the storage box, while minimizing physical damage to the specimens.

As to the pharyngeal bones and teeth which were already separated from other remains, they were all taken for further research due to the importance of analyzing cyprinids.

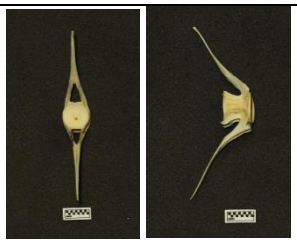
As an independent context, H1 was sub-sampled with adjusted strategy. Due to the reasons mentioned in Chapter 2, I re-analysed the fish remains from H1, focusing on vertebrae and head bones that were not previously studied. Unlike the samples from layers, the total number of fish bones was not known; therefore, sub-samples were taken by volume instead of number. The total volume of each group of bones was also measured to estimated sample size. Diagnostic elements including basioccipital of snakehead and the second vertebra of crucian carp were all picked out from the sample for quantitative analysis in next chapter.

4.2.3 Recovery strategy for mammalian remains

The retrieval of mammalian remains had experienced two stages through the excavations. The specimens from the first season of excavation were collected by hand-picking, and as a result most of them were complete bone ends and larger bone splinters. After the application of wet-sieving from the second season onwards, smaller bone fragments were also collected. All retrieved mammal bones were taken

for research.

Table 4.1 Diagnostic features of seven groups of fish vertebrae

Group	Image	Features
1		The first vertebra, usually flat and compact, with attachment surface to basioccipital.
2		The second vertebra, usually has a diagnostic shape in some species.
3		Weberian vertebrae. The third and fourth vertebra among the Ostariophysi.
4		Thoracic vertebrae. With only a fused neural spine, and ribs attached at both sides.
5		Precaudal vertebrae, with a fused neural spine and transverse processes spreading out at both sides.
6		Caudal vertebrae, with fused neural and haemel arches.
7		Ultimate vertebra, the last vertebra in the colume, with only an anterior articulation surface and the urostyle attached posteriorly.
Basioccipital		The vertebral surface on the posterior end.

4.4 Sorting

Both fish and mammalian remains are sorted into small groups for further analysis.

4.4.1 Sorting fish remains

Fish bones were sorted by sub-sample. The fish bones were first sorted into two groups, identifiable and unidentifiable specimens, and the identifiable specimens were further sorted into seven groups by anatomical locations, distinguished by the position of transverse processes: 1) first vertebra, 2) second vertebra, 3) weberian vertebrae (only appear among the Ostariophysi), 4) thoracic vertebrae, 5) precaudal vertebrae, 6) caudal vertebrae and 7) ultimate vertebra, referencing Casteel's (1976) terminology (Table 4.1). Besides, Jones and Wheeler's opinion were taken into account in the sorting and recording process, that the terms atlas and axis are deliberately avoided and replaced with first and second vertebra, because fish cannot move their heads like mammals, and using the same terms may cause misunderstanding (Wheeler and Jones, 1989). For H1 only, the identified head bones and girdle bones were sorted by element. The common diagnostic elements include premaxilla, maxillar, dentary, articular, quadrate, opercular, subopercular, basioccipital, cleithrum, parasphenoid, and vomer.

4.4.2 Sorting mammalian bones

As with fish bones, mammalian bones from each context were first sorted into the identifiable and unidentifiable specimens. The identifiable bones were then sorted by body part, including skull, maxilla, mandible, loose teeth, atlas, axis, thoracic, lumbar, sacrum, scapula, humerus, radius, ulna, metacarpal, pelvis, femur, tibia, fibula, calcaneum, astragalus and phalanges. The elements of pigs were sorted

into more detailed groups, such as into II, III, IV and V metacarpals and metatarsals.

The unidentifiable bones were sorted into a few categories, including cranial fragments, tooth fragments, vertebral fragments, ribs, carpals/tarsals and long bone shaft fragments. Each group was then sorted by animal size: large-sized mammal (e.g. water buffalo, Milu deer, samba and bear), medium-sized mammal (e.g. Sika deer, pig and panther) and small-sized mammal (e.g. water deer, muntjac, dog/dog-sized carnivore and monkeys).

4.5 Identification

Each bone fragment was identified as far as possible (e.g. to species if possible). Identification was made based on the comparison with modern and archaeological reference collections. The main reference collection is from the bone laboratory in School of Archaeology and Museology, Peking University, where both modern and archaeological specimens can be found. The advantage of using this collection is that the specimens are from native individuals so that they are comparative with the bones from Tianluoshan; on the other hand, the difference between animal populations could be reduced to the minimum by using reference collections of native animals. The other important resources for identification are the published manuals and illustrations in books. The manuals which have been used in this study are: *Atlas of animal bones for prehistorians, archaeologists and quaternary geologists* by E. Schmid (1972), *Atlas of limb-bones of mammals* by B. Gromova (Gromova, 1966, in Chinese, translated from Russian), *Fundamentals of zooarchaeology in Japan and East Asian* by A. Matsui (2001-2005), *Fauna of Neolithic age at Hemudu, Yuyao, Zhejiang* by F. Wei *et al* (1989), *Mammal bones and teeth : an introductory guide to methods of identification* by S. Hillson (1992) *Teeth* by S. Hillson (2005) and

Introduction to osteology of fishes for paleozoologists by J. Lepiksaar (1994). The online database was also instrumental in identifying fish remains (*fishbone.nottingham.ac.uk*).

However, the resources above do not completely meet the requirement of identification of fish remains from Tianluoshan, most specimens of which are not contained in either resource. Therefore, this study differed from the identification of mammalian remains, in that an adequate reference collection needed to be prepared so that the fish identification could begin.

4.5.1 The identification of fish remains – developing a reference collection

A series of reference collections are required for the purpose of fish bone identification. After searching in both Zhejiang province and Peking University, it turned out that there was no choice but to start a reference collection at the Tianluoshan, so that fish bone identification and the whole study could move on.

Initially, a few fish samples were made to begin the reference collection and more were added as they became available. The whole process follows Wheeler and Jones's instructions (1989), and changes a little according from their guidance.

All the fishes were purchased from an open air market near to Tianluoshan site. This meant that the reference collection was made up of modern farmed individuals. Usually the farm grown fish were avoided for making reference material, because: first, they were specially bred for a fast growth rate and their bones were not as diagnostic as those from natural habitats; and second, the shape of domestic fish's bones could have changed after long-term breeding. In this project, making reference collections with wild indigenous individuals was not feasible; and the practices proved that the ordinary fish from the market met the requirements of general

identification.

Considering time and budget, the reference collection was built up aiming at containing the fish species from Tianluoshan purposefully; therefore, the comparative taxa in the reference collection were decided based on previous research on the fish remains from Tianluoshan (Nakajima et al., 2011) and Hemudu (Wei et al., 1989). Four fish species were identified from the fish bone pit at Tianluoshan: *Culter alburnus* Basilewsy, *Cyprinus carpio* Linnaeus, *Carasius auratus* (Linaeus), and *Channa* spp. (Nakajima et al., 2011). I made the comparative specimens of all three taxa except for Culter fish which I could not purchase from the local market; the Channa in the reference collection was *Channa argus* (Cantor). In my first field season of this project, I realised that the fish assemblage contained more species than those identified four taxa. Referring the fish species from Hemudu, *Silurus asotus* Linnaeus, *Aristichthys nobilis* (Richardson), and *Mylopharyngodon piceus* (Richardson) were added to the collection. Plus, two common local fish, *Lateolabrax maculatus* (McClelland) and *Monopterus albus* (Zuiew), were added. Unfortunately, Culter was hard to get due to overfishing and the damage of their natural habitat. Culter was identified using literature references (Nakajima et al., 2011). In the end, the reference collection contained eight species: *Cyprinus carpio* Linnaeus (common carp), *Carasius auratus* (Linaeus) (crucian carp), *Mylopharyngodon piceus* (Richardson) (black carp), *Aristichthys nobilis* (Richardson) (big-head carp), *Silurus asotus* Linnaeus (catfish), *Channa argus* (Cantor) northern snakehead, *Lateolabrax maculatus* (McClelland) (sea bass), and *Monopterus albus* (Zuiew) (freshwater eel). Black carp, big-head carp, and eel were not found in the Tianluoshan fish assemblage.

Table 4.2 List of modern comparative specimens, place of collection, and size.

Species	**Place of collection**	**Total Length (mm)**	**Fork Length (mm)**	**Standard Length (mm)**	**Head Length (mm)**	**Body Depth (mm)**	**Total Weight (g)**	**Gutted Weight (g)**	**Skeletal parts for identification**
Cyprinus carpio	Yuyao, Zhejiang	556	496	460	120	496	2000	1600	Articular, basioccipital, ceratohyal, cleithrum, cranial bones, dentary, epihyal, interopercular, maxilla, opercular, parasphenoid, pharyngeal bone, premaxilla, quadrate, subopercular, vertebral column, vomer
Carasius auratus	Yuyao, Zhejiang	289	265	240	57	93	448	350	Articular, basioccipital, ceratohyal, cleithrum, cranial bones, dentary, epihyal, interopercular, maxilla, opercular, parasphenoid, pharyngeal bone, premaxilla, premaxilla, quadrate, subopercular, vertebral column, vomer
Carasius auratus	Yuyao, Zhejiang	250	225	195	485	785	300		Articular, basioccipital, ceratohyal, cleithrum, cranial bones, dentary, epihyal, interopercular, maxilla, opercular, parasphenoid, pharyngeal bone, premaxilla, premaxilla, quadrate, subopercular, vertebral column, vomer

Channa argus	Yuyao, Zhejiang,	410	Null	360	103	60			Articular, basioccipital, ceratohyal, cleithrum, cranial bones, dentary, epihyal, interopercular, maxilla, opercular, parasphenoid, premaxilla, quadrate, subopercular, vertebral column, vomer
Channa argus	Yuyao, Zhejiang	320	Null	275	89	37		217	Articular, basioccipital, ceratohyal, cleithrum, cranial bones, dentary, epihyal, interopercular, maxilla, opercular, parasphenoid, premaxilla, quadrate, subopercular, vertebral column, vomer
Channa argus	Yuyao, Zhejiang,	235	Null	205	66	29		89	Articular, basioccipital, ceratohyal, cleithrum, cranial bones, dentary, epihyal, interopercular, maxilla, opercular, parasphenoid, premaxilla, quadrate, subopercular, vertebral column, vomer
Channa argus	Yuyao, Zhejiang,	400	Null	350	90	45		500	Articular, basioccipital, ceratohyal, cleithrum, cranial bones, dentary, epihyal, interopercular, maxilla, opercular, parasphenoid, premaxilla, quadrate, subopercular, vertebral column, vomer

Channa argus	Yuyao, Zhejiang	400	Null	340	115	55	570	545	Articular, basioccipital, ceratohyal, cleithrum, cranial bones, dentary, epihyal, interopercular, maxilla, opercular, parasphenoid, premaxilla, quadrate, subopercular, vertebral column, vomer
Channa argus	Yuyao, Zhejiang	290	Null	245	80	40	180	160	Articular, basioccipital, ceratohyal, cleithrum, cranial bones, dentary, epihyal, interopercular, maxilla, opercular, parasphenoid, premaxilla, quadrate, subopercular, vertebral column, vomer
Channa argus	Yuyao, Zhejiang	350	Null	300	90	55	375	355	Articular, basioccipital, ceratohyal, cleithrum, cranial bones, dentary, epihyal, interopercular, maxilla, opercular, parasphenoid, premaxilla, quadrate, subopercular, vertebral column, vomer
Silurus asotus	Yuyao, Zhejiang	375	Null	337	70	65			Articular, basioccipital, ceratohyal, cleithrum, cranial bones, dentary, epihyal, interopercular, maxilla, opercular, parasphenoid, premaxilla, quadrate, subopercular, vertebral column, vomer

Aristichthys nobilis	Yuyao, Zhejiang								Articular, basioccipital, ceratohyal, cleithrum, cranial bones, dentary, epihyal, interopercular, maxilla, opercular, parasphenoid, pharyngeal bone, premaxilla, quadrate, subopercular, vertebra 1-4, vomer
Mylopharyngodon piceus	Jiaxing, Zhejiang								Articular, basioccipital, ceratohyal, cleithrum, cranial bones, dentary, epihyal, interopercular, maxilla, opercular, parasphenoid, pharyngeal bone, premaxilla, quadrate, subopercular, vertebral column, vomer
Lateolabrax maculatus	Hangzhou, Zhejiang								Articular, basioccipital, ceratohyal, cleithrum, cranial bones, dentary, epihyal, interopercular, maxilla, opercular, parasphenoid, premaxilla, quadrate, subopercular, vertebral column, vomer
Monopterus albus	Yuyao, Zhejiang							125	Head bones as a whole, vertebral column

The reference specimen making process is described as follows.

First, colour photographs of each fish were taken before preparation commenced. Several measurements were taken next: total length, fork length, standard length, body depth, and head length. The total and gutted weights of the fish were also recorded.

After recording the data above, the fish were put into a stainless steel pot and boiled for 5 to 10 minutes. After several practice attempts, I found out that the best time for boiling is up to 10 minutes. For bigger fish like the carp and snakehead, 10 minutes is enough cook the fish thoroughly, so that the flesh could be easily removed. However, tissues from different parts are affected unequally, such as the enamel of pharyngeal teeth will have already shed from the bones, while most of the bones need to be soaked in alkaline solution for another 7 to 10 days and brushed gently to remove the attached soft tissue. For smaller and more delicate fish such as crucian carp, the cooking time should be shortened according to size.

The first crucian carp which is 28 cm long was boiled at the same time with other carp in separate bags. The whole body almost fell apart when taking the skeleton out of the bag after ten-minutes boiling. Even the skull bones were loosened. Boiling makes it easier to clean bones, but the bone tissue can be destroyed by long boiling times.

With experience gained, the rest of the fish, which are much smaller, were cooked only for 5 minutes.

The next step was to remove the flesh and connective tissues, using tweezers, chopsticks, needles and other applicable tools. When the flesh was removed, the skeleton was soaked in alkaline solution, which was a washing powder solution in my

case, for 5 to 7 days in winter, 1 to 2 days in summer, in order to clean the remaining connective tissues. Apparently higher temperatures accelerates the decomposition process. The solution should be changed regularly during the soaking procedure.

When removing bones from the skeleton, elements from each side of the body are better kept in separate trays. The head bones should be removed piece by piece, and put in the right position to avoid confusion; so are the vertebrae. When detaching vertebrae from the basioccipital and each other, a thin blade should be used.

The last step of the process is to mark each bone with its element name and body side, and string the vertebrae in the right order. The reference collection is then ready to use for identification purposes.

4.5.2 Identification using reference collections

The identification of each bone was done mainly by comparing the specimen with the specimens in reference collection. Since the fish bone remains at Tianluoshan are biased in terms of skeletal part, pharyngeal bone and the vertebrae column are the elements which are used most frequently.

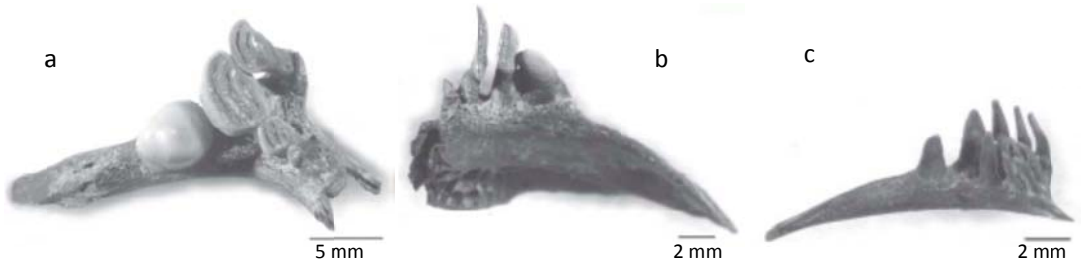
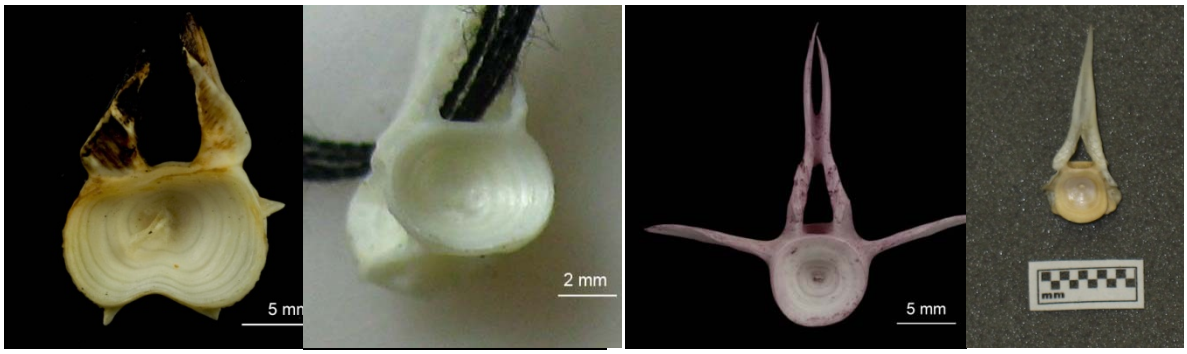


Figure 4.2 Pharyngeal bones of Cyprinids at Tianluoshan, from left to right, common carp (a), crucian carp (b) and top-mouth culter (c).

The pharyngeal bones show great differences between species (Figure 4.2). However, the bony part of the pharyngeal bone is usually shattered, so the

identification mostly relies on the teeth.

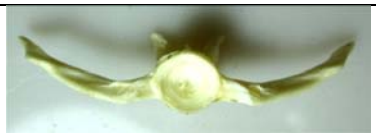


a b c d

Figure 4.3 The comparison of anterior abdominal vertebrae (group 4) of common carp (a), crucian carp (b), catfish (c) and snakehead (d). Photo (a) and (c) are from the online database *fishbone.nottingham.ac.uk*

The vertebrae also show distinct variations between species. The features for observation are: shape of anterior and posterior articulating surface, shape of transverse processes and dorso-ventral axis, the position of ridges or foramina on the sides of the centrum, and the constructional pattern on the surface of vertebrate centrum. For example, the articulating surface of carp thoracic vertebra is kidney-shaped, but the shape of the surface of crucian carp is oval and with fewer processes. As to catfish, the transverse processes spread from the base of dorso-ventral axis, much higher than in the other fish. Like mammals, the first two vertebrae of fish are the most significant vertebrae for identification. Comparing them, fish vertebrae tend to lose diagnostic characteristics towards the caudal end (except the penultimate vertebra). Therefore, in this study, considering all the factors, two elements, the basioccipital and the second vertebra, are given much more attention during identification, because 1) they are possible to identify with a high degree of certainty; 2) they are appropriate elements for counting MNI; 3) they allow accurate and reproducible measurement.

Table 4.3 Characteristics of the second vertebra of common carp versus crucian carp: observations resulting from the current study

		Common carp	**Crucian carp**
Photos	Ventral view		
	Anterior view		
Centrum	General	Wide and shorter	Slim and longer
	Ventral view	Curve at frontal edge	Flat at frontall edge
	Notches	Narrow	Wide
articulation surface	Anterior view	Almost oval. Ventral edge close to obtuse angle.	Almost pentagon.
Transverse processes	Anterior view	About 2/5 to ventral edge	Closer to ventral edge, about 1/4 part
	shape	Spread horizontally	Not horizontal
	Ventral/dorsal view	Almost right angle with vertebral column; turn to a sharp angle near the end of the processes	Sharp angle with vertebral column. The tip of process arrives at the extension surface of the posterior articulating surface.

As there were barely any pharyngeal teeth of crucian carp collected from the deposits, the second vertebra was used for counting MNI. Normally the second vertebrae of crucian carp and common carp can be told apart by size, but the vertebrae of small common carps and average sized crucian carps share many similarities, especially when the archaeological samples are incomplete. Before the recording started, the second vertebrae of both species were studied carefully, and the comparative morphological features were listed (Table 4.3). Each specimen could be safely identified with these criteria.

Table 4.4 The diagnostic skeletal elements used by each individual taxon. Elements which are not used in this project is not listed in this table.

Species	Diagnostic skeletal elements
Cyprinus carpio Linnaeus	1st dorsal fin spine, articular, basioccipital, dentary, epihyal, hyomandibular, interopercular, maxilla, opercular, pharyngeal bone, premaxilla, preopercular, quadrate, urohyal, subopercular, vertebra group 1 – 7.
Carassius auratus (Linnaeus)	1st dorsal fin spine, articular, basioccipital, basipterygium, ceratohyal, cleithrum, dentary, epihyal, hyomandibular, interopercular, maxilla, opercular, pharyngeal bone, parasphenoid, premaxilla, preopercular, quadrate, urohyal, subopercular, vertebra group 1 – 7.
Channa argus (Cantor)	Basioccipital, dentary, premaxilla, urohyal, vertebra group 1-7, vomer.
Silurus asotus Linnaeus	Basioccipital, dentary, premaxilla, vertebra group 1-7.
Lateolabrax japonicas (Cuvier et Valenciennes)	Basioccipital, vertebra group 1-7.

The diagnostic element for the identification and analysis of snakehead is bioccipital, which is located at the base of skull, connected to the first vertebra. It is usually found as a cone shaped sturdy fragment with articulation surface and intense parallel lines on the ventral side (Table 4.1). The vertebrae of snakehead share similar characteristics on the appearance. Their shape changes gradually from the first vertebra to the last; even the first vertebra, which most of the time is diagnostic, is easily mistaken with the next few.

4.5.3 The identification of mammalian remains

The mammals at Tianluoshan are mainly from four orders, ten families, requiring a reference collection with large capacity. Fortunately many of the species could be found at Peking University; the illustrations in *Fauna of Neolithic age at Hemudu, Yuyao, Zhejiang* (Wei et al., 1989) were useful as comparatives.

The difficulty of identifying mammals from Tianluoshan was the identification of several species of deer and carnivores. Deer species were identified mainly by antlers and dentition. Size was a simple but efficient indication for identification. Generally, the largest were sambar (*Cervus unicolor*) and Milu deer (*Elaphurus dividianus*), the medium sized were sika deer (*Cervus nippon*), and the small sized (about dog size) were muntjac (*Muntiacus reevesi*) and water deer (*Hydropotes inermis*). The average size of water deer is slightly larger than muntjacs; since water deer do not grow antlers, size has become important for identifying limb bones. We must bear in mind, however, that animal/species size may have changed over time.

A few species of carnivores can be identified with the aid of reference collections at Peking University, while others are identified using reference books. The comparable illustrations of dentition for all carnivore species at Tianluoshan can be found in *Fauna of Neolithic age at Hemudu, Yuyao, Zhejiang*. The identification of limb bones was mostly done consulting the sketches in *Fundamentals of zooarchaeology in Japan and East Asian* (Matsui, 2001-2005).

4.6 Recording

4.6.1 Recording fish specimens

Each database record for fish bone includes 10 fields: context number, sample number, species, element, side of body, measurement, completeness, burn, burn location, and weathering. Measurements are taken on a few elements which were chosen according to the criteria listed in section 3.3.5 of Chapter 3, including basioccipital, the first and the second vertebrae. The number of possible measurements taken per specimen varies, for example, two measurements are taken

on the basioccipital at the posterior end, the width and height of the articulation surface; but for the second vertebra, the length of the centrum is also measured beside of the measurements of the articulation surfaces. Measurements were taken with dial calipers accurate to 0.02mm.

4.6.2 Recording mammalian specimens

For each specimen of mammal bones, 11 features are recorded, including context number, sample number, taxon of animal, element, side of body, number of pieces, sex, age, fusion condition, modifications (gnawing, weathering, burning, worked, butchery marks, etc.) and measurements. Sex and age can only be identified on specific elements, such as pelvis and mandibles. Measurements were taken on mandibles, limb bones and teeth, following von don Driesch's instructions (1976). Attrition of mandibular teeth was recorded for age profiling. Varied coding systems were applied on different species, following previous research. The attrition of pig teeth was recorded according to Grant's (Grant, 1982) Tooth Wear Stage (TWS) recording system; for sika deer, Ohtaishi's (Ohtaishi, 1980, Koike and Ohtaishi, 1985) tooth wear index was used; and the tooth wear of muntjac was recorded following Chapman and colleagues' (Chapman et al., 1985, Chapman et al., 2005) scoring method.

4.7 Quantification

Two fundamental quantitative units, Number of Identified Specimens (NISP) and Minimum Number of Individuals (MNI) are used to measure the taxonomic abundances of both fish and mammalian remains.

NISP is the most fundamental unit that faunal remains are tallied by the number

of identified specimens, as is stated in the name. MNI, on the other hand, is a derived quantitative unit. Each of the methods has both advantages and disadvantages, for example, NISP may repeatedly count the same bone due to fragmentation, and MNI may exaggerate the importance of minority species. In the case of Tianluoshan, the analysis will mainly rely on NISP, considering that each specimen of fish remains is usually a whole bone, and the mammalian specimens are unusually complete. MNI will also be tallied for further discussion.

In the quantification of fish remains, a big issue to deal with is the selecting of coarse-sieved and fine-sieved samples. Taking the same T105 Layer-7 that was mentioned above for example, the total 346 specimens from coarse sieving were all taken as a sub-sample; a sub-sample containing 300 specimens were taken from 14980 fine-sieved specimens. Both sub-samples were sorted, identified and recorded following the steps above. The analysis in next chapter will show that the relative abundance of both sub-samples differs a lot. If only the sub-samples were quantified, the importance of coarse-sieved specimen would be exaggerated, while the fine-sieved sample, which is the actual major part of the whole sample, will be overlooked, causing a bias in the results.

Therefore, a mathematic method was used to adjust the sample size to the original. The equation shows how to calculate the NISP of species (N_{sp}) in a sample.

$$N_{sp} = n_c \times \frac{S_c}{s_c} + n_f \times \frac{S_f}{s_f} + n_{basio}$$

n = NISP of the species in a sub-sample; S = sample size; s = sub-sample size; c = coarse-sieving; f = fine-sieving; n_{basio} refers to the number of basioccipitals in the separated group.

In sample T105 Layer-7, $n_c$of snakehead is 280, n_f of snakehead is 203, so:

$$N_{snakehead} = 280 \times \frac{346}{346} + 203 \times \frac{14885}{300} + 88 = 10440$$

Accordingly, the NISP of other species in T105 Layer-7 were calculated in the same way. The total number of a species in a stage is calculated by adding the NISP of that species in each context together, and these are the statistics for the analysis of relative importance in the next chapter.

4.8 Data processing

Different methods are employed in the data processing of fish and mammalian remains due to topics. For mammalian remains, methods are developed to profile the age of animal from skeletal parts, and subsequently estimate the hunting season and discuss hunting strategies. Primarily the most abundant three mammals, muntjac, sika deer and pigs are profiled, using different ageing methods.

Methods for processing data of fish remains aim to solve two issues: to estimate the original body length of the fish individuals, and to decide the fishing season(s).

4.8.1 Body length reconstruction and seasonality estimation using fish remains

The methods for size reconstruction have been summarized in Chapter 3. This section will be the application of these methods to the ichthyofaunal remains of Tianluoshan. Only original body length of fish will be derived; weight estimation will not be discusses.

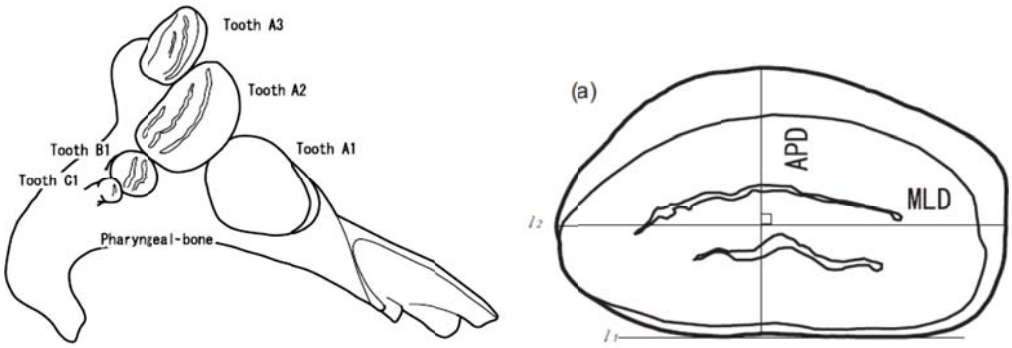
The original body lengths of fish individuals were derived using the single regression method with measurements of reference specimens and skeletal elements. The size of three predominant fish will be discussed: common carp,

crucian carp and snakehead. Considering the survivorship of the elements of these various species, different elements were chosen between species. For common carp, the size of pharyngeal teeth will be used; for crucian carp, the second vertebra will be used; and the basioccipital of snakehead will be used.

4.8.1.1 Common carp (Carpio carpio)

A diagnostic feature of cyprinids is that they have well developed throat dentition on pharyngeal bones instead of teeth in the oral cavity. The external form, number and layout of pharyngeal teeth differ between species in Cyprinidae, thus, they are used as significant criteria for classification, and identification in zooarchaeology.

Pharyngeal teeth from H1 the fish bone pit have been researched by Nakajima and colleagues (2011, 2010a), and a single regression equation showing in relation with the size of pharyngeal tooth and estimated body length of fish was presented, based on measurements of modern specimens. Their equation and data will be used in the body length reconstruction of common carp from stratigraphic layers, so the results will be in consistence with those in previous research.



(a) (b)

Figure 4.4 Pharyngeal bone and the measurements on the objective tooth A2. (a) The right pharyngeal bone of common carp with teeth that locate in three rows; (b) Two measurements on A2: mesio-lateral diameter (MLD) and antero-posterior diameter (APD); in this study, only MLD is taken. Reproduced from Nakajima *et al* (2010).

In Nakajima and colleague's research, the correlation between the length of A2 (Figure 4.7) and the body length was derived from modern specimens, showing as follows:

$$BL_{MLD} = 18.2 + 57.6 \times \mathrm{MLD}$$

By measuring the MLD on archaeological specimens, the body length of that individual can easily be calculated.

4.8.1.2 Crucian carp

The single regression method was also used to estimate the body length of crucian carp, with measurements of the second vertebra. Basically the single regression equation was still derived from modern reference specimens, but indirectly, using Nakajima's research on the crucian carp in H1 as the intermediate.

Nakajima and colleagues had analysed the crucian carp remains from H1, using the same method that were applied in the research of common carp (Nakajima et al., 2010a, 2011). The measured width of pharyngeal tooth A1 (Figure 4.5) was used for reconstructing body length. However, the correlation between A1 and body length was not applicable to the crucian carp remains in layers, where very rare A1 was retrieved, possibly due to small size and inconspicuous shape.

I decided to choose the second vertebra for body length estimation, overall considering several factors. First, it is diagnostic to be easily identified to species with the aid of reference collection. Second, it tallies with the criteria for taking measurement in Chapter 3. At last, it is the most abundant vertebra of crucian carp in the assemblage, more than the first vertebra which is also diagnostic and compact, possibly caused by the sieving and collecting processes. My first thought was to take measurements of the second vertebra on the modern specimens that were used in

Nakajima *et al*'s analysis, but I could not get access to them; so I decide to connect my measurements to the reference data through the intermediate existing studies.

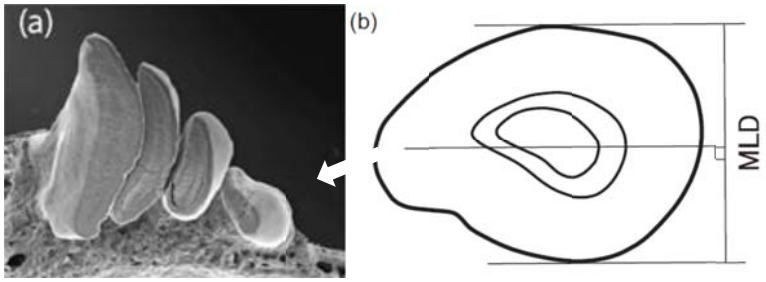


Figure 4.5 Right pharyngeal bone of crucian carp from Tianluoshan (a) and the measurement diagram of A1 (b). The scale bar in (a) is 1mm. Reproduced from Nakajima *et al* 2010.

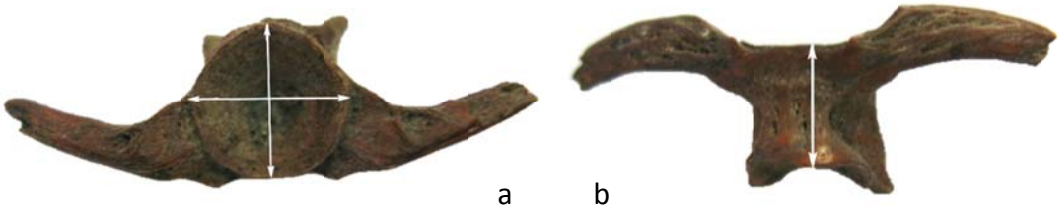


Figure 4.6 Measurements on the second vertebra of crucian carp. Width and height of the anterior articular surface (a) and the ventral length of the centrum were taken (b).

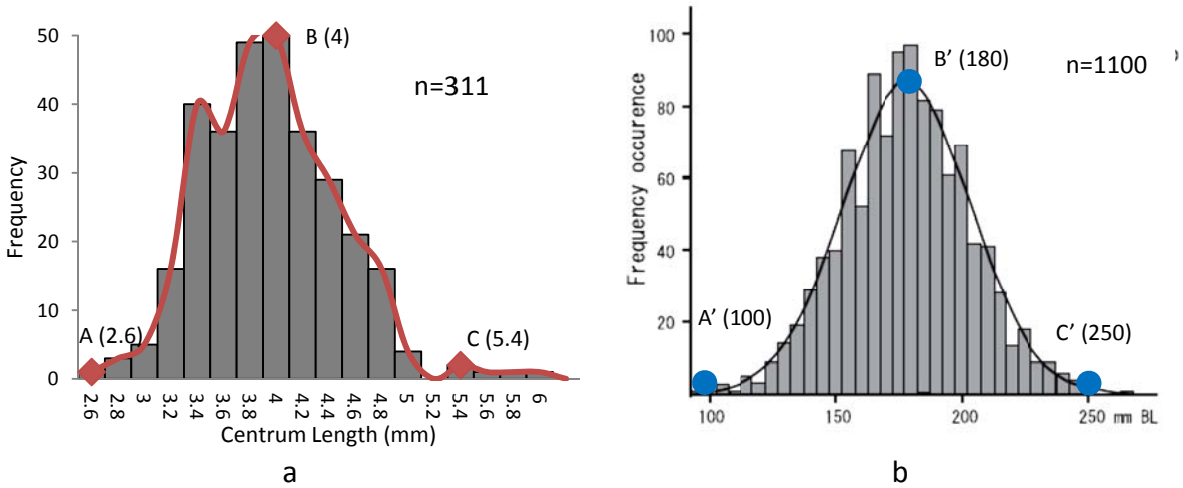


Figure 4.7 The corresponding distributions of crucian carp in H1 at Tianluoshan: (a) the measured centrum length of the second vertebra, and (b) body length distribution estimated from pharyngeal tooth, reproduced from Nakajima *et al* 2010.

The basic idea was to find out the correlation between sizes of second vertebra and body length using the published data of crucian carp in H1. The process was presented step by step as follows.

1) Three measurements were taken on the second vertebra (Figure 4.6) using callipers accurate to 0.1 mm and recorded. Considering that body length was possibly more relevant to the length of vertebrate centrum, I chose this measurement over the width and height of the anterior articulation surface. The latter measurements were saved for future research.
2) A total number of 311 vertebrae were measured, about a quarter of measured pharyngeal teeth (NISP=1101, including 675 from the left side and 626 from the right side) or MNI of crucian carp (1431) in H1. The frequency distribution of centrum length (CL) is shown in Figure 4.7a.
3) Since pharyngeal teeth and the second vertebra in H1 were from the same population, theoretically, the frequency distribution by the size of the second vertebra should be the same as Nakajima's distribution (Figure 4.7b), and the points located at the same position in two distribution curves should be in correspondence with each other, e.g. the peak point. Therefore, I marked three pairs of corresponding points in two distribution curves, A-A', B-B', and C-C', and estimated their horizontal ordinates as follows:

   CL(A) = 2.6 mm, CL(B) = 4.0 mm, CL(C) = 5.4mm

   BL(A') = 100 mm, BL(B') = 180 mm, BL(C') = 250 mm

4) Assuming that the single regression equation for centrum length (CL) on second vertebra and the body length of crucian carp is:

$$\mathrm{BL} = \mathrm{a} \times \mathrm{CL} + \mathrm{b}$$

Substitute the values in last step into the equation and solve, we can get the index:

a = 52.69, b = 28.77.

Therefore, the final single regression equation for estimating body length of crucian carp using centrum length of the second vertebra is:

$$\mathrm{BL} = 52.69 \times \mathrm{CL} - 28.77$$

4.8.1.3 Snakehead

Snakeheads from archaeological sites have been rarely recorded and studied. Data on the growth of snakehead and annulus formation in vertebrae were not found in the literature, therefore, a reference collection of modern wild snakeheads is required for body length reconstruction and seasonality assessment. After trying many resources, I was able to acquire 22 wild snakeheads with the help of Institute of Hydrobiology, Chinese Academy of Science (IHB).

Table 4.5 Measurements of modern snakeheads used for the construction of snakehead size regression curve.

No.	Month of capture	Age	Total length(cm)	Standard length(cm)	Body depth(cm)	Head length(cm)	Width (mm)	Height (mm)
1	Jan	4(3+)	308	261	54	86	5.68	5.02
2	Jan	5(4+)	442	380	67	123	7.78	7.08
3	Feb	4(4)	318	274	50	87	5.3	5.12
4	Feb	4(4)	331	284	57	94	5.84	5.56
5	Mar	3(3)	307	263	51	85	4.65	4.04
6	Mar	3(2+)	270	236	45	76	4.74	4.03
7	Mar	4(4)	331	282	48	90	6	5.05
8	Apr	4(3+)	340	292	58	105	6.94	6.13
9	Apr	5(4+)	385	331	69	120	7.33	6.63
10	Apr	2(1+)	206	174	34	61	3.41	2.98
11	Apr	4(4)	367	314	62	106	6.24	5.9
12	May	3(3)	290	250	40	66	4.18	3.87
13	May	3(3)	243	200	38	64	3.93	3.78
14	May	5(4+)	363	305	62	100	6.57	5.8
15	May	2(1+)	210	179	33	62	3.25	2.7
16	May	2(1+)	188	158	29	57	3.5	3.21
17	May	4(3+)	296	255	52	84	4.63	4.35
18	Jun	4(3+)	309	260	51	89	5.72	4.85
19	Jun	3(2+)	258	221	43	72	4.39	4.09
20	Jun	4(3+)	308	259	51	86	5.26	5.15
21	Jun	4(3+)	287	244	48	81	4.82	4.62
22	Jul	5(4+)	497	430	74	132	6.14	5.47

Reference specimens were gathered from lakes in Hubei Province, in the Middle Yangtze River Region, following the sampling strategy in Van neer and colleagues' study (Van Neer et al., 1999, P120, van Neer et al., 2004, P459). From December 2012 to July 2013, monthly samples of 22 snakehead specimens were obtained and processed by the IHB. They were used for both construction of snakehead length regression curve and estimation of fishing season. Measurements of body size, including total length, standard length, body depth, and head length, were taken on each fish. After processing, the width and height of each basioccipital were measured, and the annuli distribution on basioccipital was photographed as reference. All measurements are shown in Table 4.5.

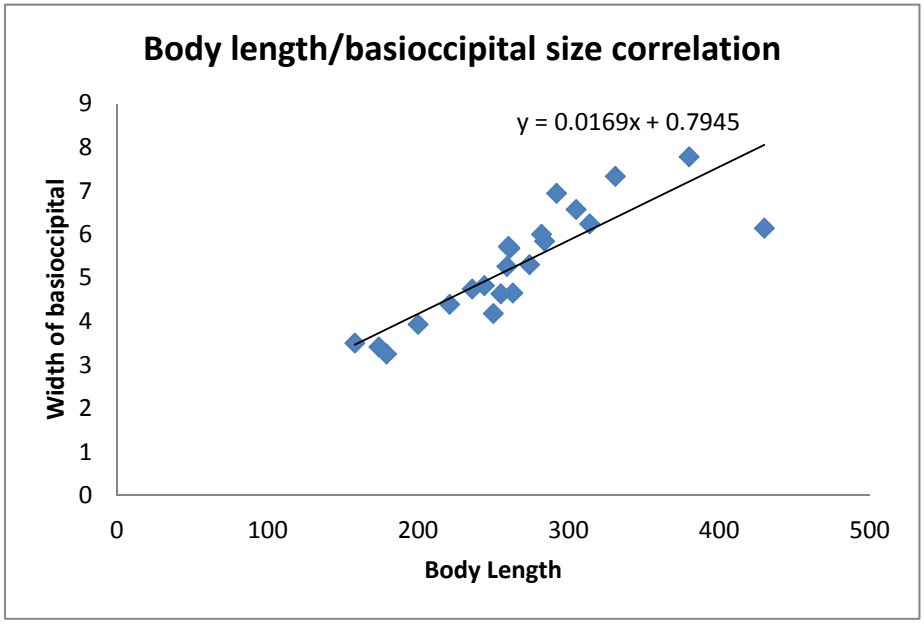


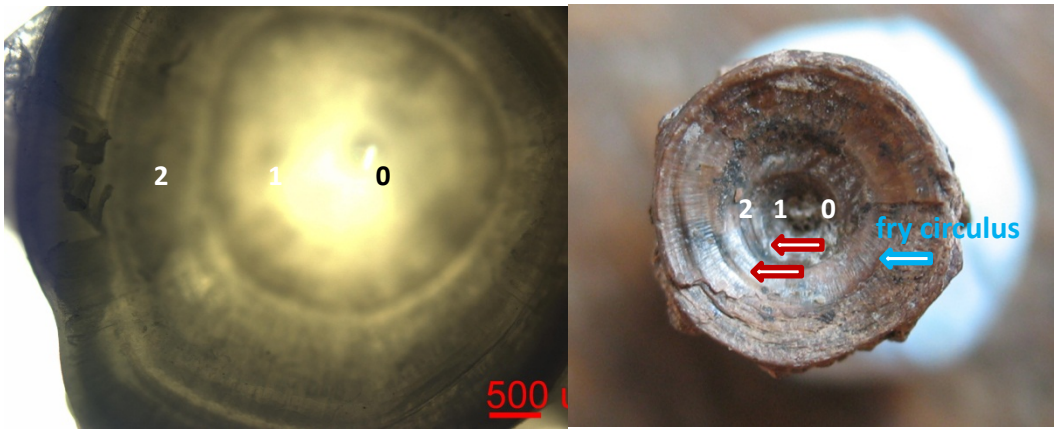
Figure 4.8 Regression analysis between body length (standard length) and the width of snakehead basioccipital.

Body length reconstruction:

The single regression method was used to reconstruct the original body length of snakehead from the size of basioccipital. The correlation between body length and the width of basioccipital was derived from metric data of modern

snakeheads, shown in Figure 4.8. A single regression equation is derived accordingly:

$$\mathrm{BL} = 59.17W_{basio} - 47.01$$



(a) (b)

Figure 4.9 Annuli on the articulation surface of modern snakehead (a) and archaeological specimen (b). The modern specimen is taken from a 2 years old snakehead which is caught in July. The outermost circle refers to the newly grown part. The archaeological specimen shows similar annuli and outer margin, indicating that it was caught approximately at the same season as the modern specimen. A false annulus is also visible in the photo.

4.8.1.4 Seasonality assessment:

The methods for seasonality assessment using fish bones have been summarized in Chapter 3. From the methods, I chose to estimate cull seasons from the pattern of the outermost annulus on the articulation surface of basioccipital, by comparing archaeological specimens to modern reference specimens. Study of the modern snakehead collection implies that the new annulus normally appears in spring, from February to May, mostly in February. The margin outside of the latest annulus refers to the newly grown bone structure. the archaeological specimen in Figure 4.9 shows similar annuli distribution and outer margin to the modern specimen, meaning that it is possibly at the same ages and was caught in July, the same as the reference specimen.

4.8.2 Age profiling of the mammalian remains

In the study of mammalian remains from Tianluoshan, only mandibles with teeth, mostly molars, are used for ageing pig, sika deer and muntjacs. For the juvenile individuals, their age can be decided from the eruption and replacement sequence of teeth. The age of adult individuals is decided from the tooth wear pattern, which has been well developed in the past decades, especially for domestic animals. The methods for ageing pig, sika deer and muntjacs are presented as follows.

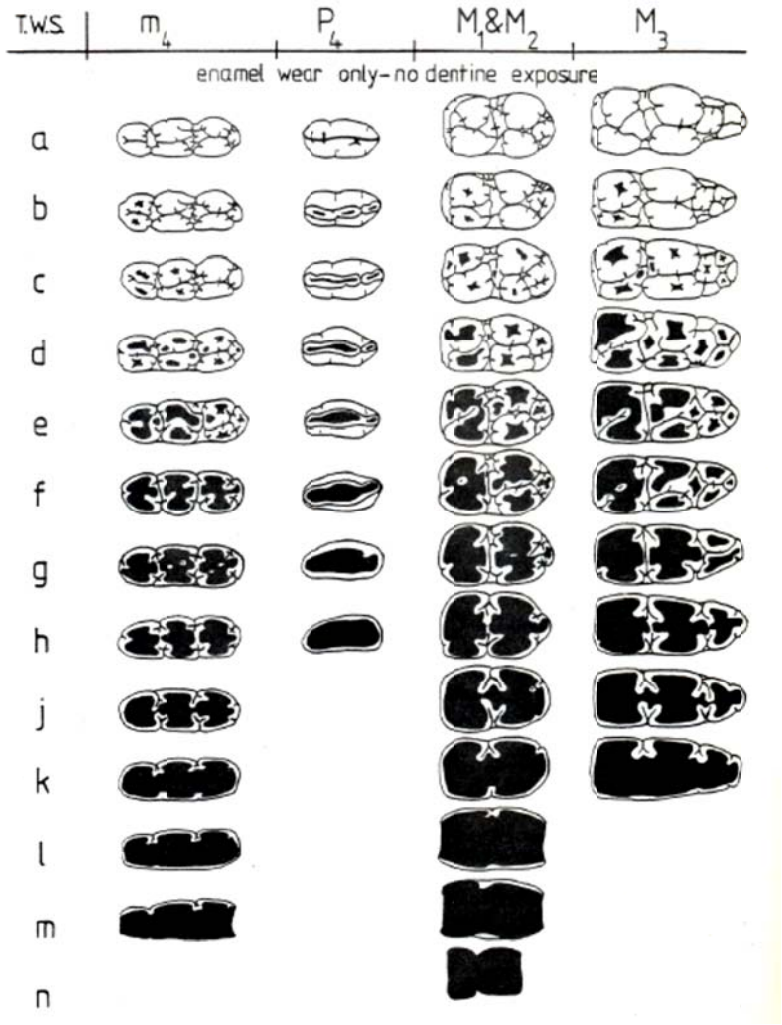


Figure 4.10 Tooth wear stages of pig teeth, from Grant (1982).

4.8.2.1 Pig

There have been plenty of studies on ageing pig remains, which is important for investigating the husbandry process. Piglets can be identified to a precise age by

observing tooth eruption and replacement. The tooth wear patterns of adult individuals were recorded following Grant's (1982) Tooth Wear Stage (TWS) recording system (Figure 4.10), and the attrition of molars were added together as the Mandible Wear Stage (MWG), which eventually showed the age of the individual.

There has been a discussion about whether the pigs at Tianluoshan are wild or domesticated. The ageing results will be compared with records of wild individuals (Bull and Payne, 1982), and discussed.

Table 4.6 Tooth eruption and replacement in mandible of Sika deer. From Koike and Ohtaishi (1985)

Winter	**Age (years)**	**Teeth eruption**
	0	$i_1\ i_2\ i_3\ c\ dp_1\ dp_2\ dp_3$
1st	0.5	$i_1\ i_2\ i_3\ c\ dp_1\ dp_2\ dp_3\ M_1$
	1.0	$i_1\ i_2\ i_3\ c\ dp_1\ dp_2\ dp_3\ M_1\ M_2$
2nd	1.5	$I_1\ I_2\ i_3\ c\ dp_1\ dp_2\ dp_3\ M_1\ M_2$
	2.0	$I_1\ I_2\ I_3\ C\ dp_1\ dp_2\ dp_3\ M_1\ M_2\ M_3$
3rd	2.5	$I_1\ I_2\ I_3\ C\ P_1\ P_2\ P_3\ M_1\ M_2\ M_3$

4.8.2.2 Sika deer

The studies of ageing wild animals are much less than that of domestic animals. As a sacred animal in Nara city and common prey in Japanese Jomon, sika deer had been studied thoroughly by Japanese biologists and archaeologists. The age of juvenile individuals (approximately from new-born to 2.5 years old) were decided from tooth eruption and replacement sequence, which was presented by Koike and Ohtaishi (1985) based on the observation of 1700 mandibles of living deer throughout Japan (Figure 4.3). The age of sika deer can be assessed with three methods: tooth wear index (Ohtaishi, 1980, Koike and Ohtaishi, 1985), tooth scoring method (Brown and Chapman, 1990, 1991), and tooth height method (Klein et al.,

1981). Due to the lack of reference sample by tooth height, the combination of the other two methods will be used for ageing sika deer from mandibles.

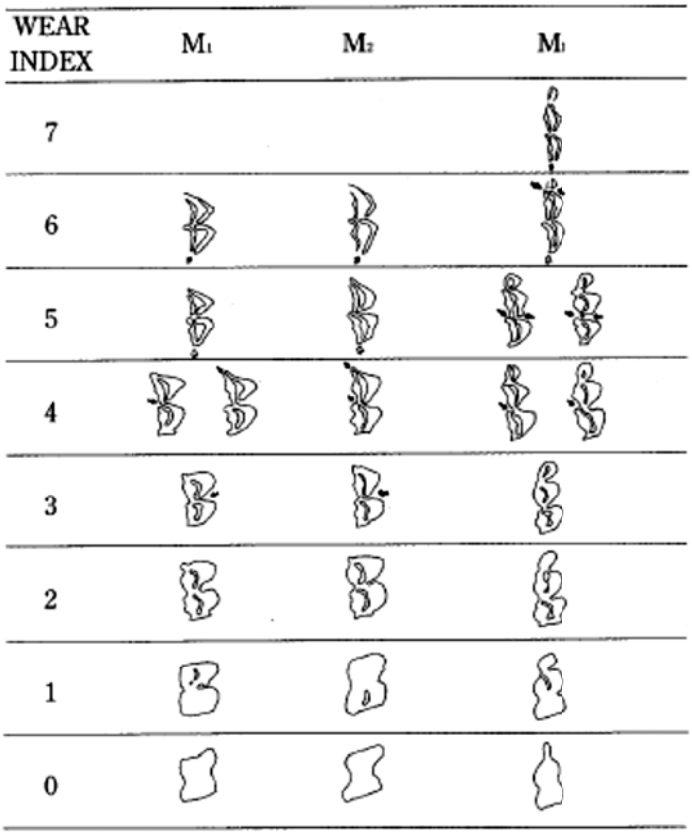
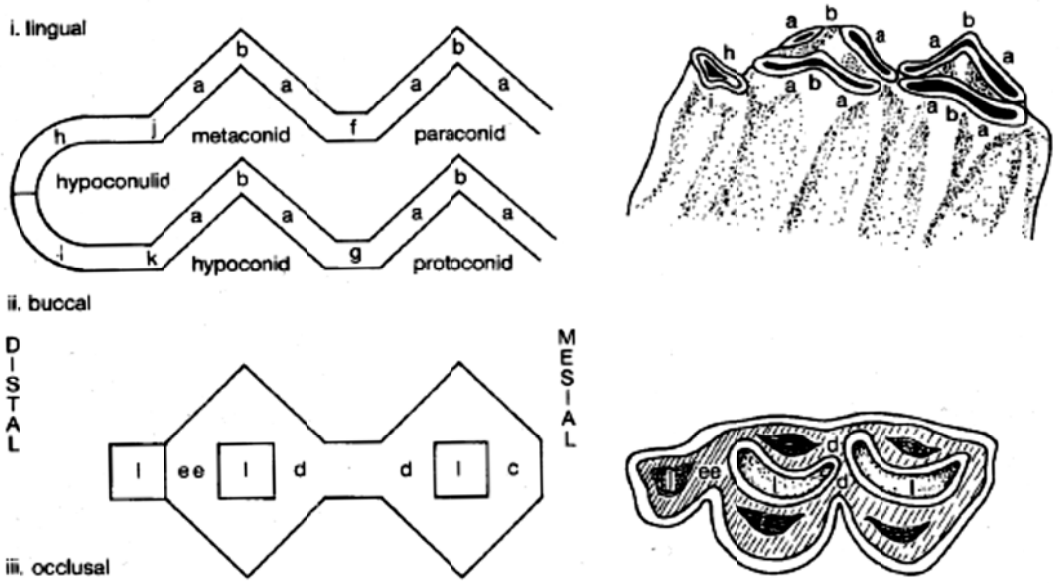


Figure 4.11 Tooth wear patterns of sika deer molars, with '7' and '6' representing slight wear, and '0' representing the heaviest wear. Arrows refer to the key points for identification, i.e. the continuation of cusps by dentine tissue. From Ohtaishi (1980).

In Ohtaishi's tooth wear index system, the wear on occlusal surface of molar was recorded with code '0' to '6', a plus '7' for M3, which represented the a sequence change from slightly worn (6 and 7), to heavily worn (0 and 1) (Figure 4.11). After being examined by multivariate test, the relation between combined wear index of molars and age was built (Table 4.4). Therefore, age of archaeological specimen can be estimated by comparing the wear pattern to the chart and table.

Brown and Chapman used a scoring scheme to record the wear of tooth and estimate the age of specimen accordingly. This method has been applied to the

research of red deer, fallow deer, and muntjac with a modified version (see below). Generally, each feature on the occlusal surface that was caused by wear was granted a certain score (Figure 4.12); hence, each molar or premolar had a score by adding all the numbers together. Applying the scoring method to Ohtaishi's tooth-wear-index/age system, the results are shown in Table 4.4.



Type of wear	Location	Score
Enamel wear on cusp slopes	a	1
Dentine wear on cusp slopes	a	2
"Central eye" between slopes	b	1
Dentine links between lingual and buccal cusps:		
i. mesial ridge	c	1
ii. between mesial and distal cusps	d	1
iii. distal ridge	e	1
Dentine links between mesial and buccal cusps:		
i. lingual aspect	f	1
ii. buccal aspect	g	1
Third molar hypoconulid dentine exposed:		
i. lingual aspect	h	1
ii. buccal aspect	i	1
iii. distal linking of i. and ii.	h&i	1
iv. link with lingual cusp	j	1
v. link with buccal cusp	k	1
vi. link between lingual and buccal cusps	e	1
All infundibulum worn away	l	1
Black staining of exposed dentine		1

Figure 4.12 Tooth wear scoring scheme for red deer and fallow deer, showing the scoring locations and points. From Brown and Chapman (1991: P524)

Table 4.7 Combined teeth indices, probabilities, and teeth wear scores of sika deer of age 0.5 to 8.5, estimated from cement annuli. Summarized from Koike and Ohtaishi (1985), Brown and Chapman (1990, 1991), and Uchiyama (1999).

Age	**Tooth wear index**			**Probability**	**Total score**
	M1	**M2**	**M3**		
0.5	6	7*	8*	0.99	28
1.5	5 (6)	6	8	0.99	57
2.5	4 (5)	5	7	0.94	86
3.5	3 (4, 5)	5 (3, 4, 6)	6	0.79	91
4.5	2 (3)	4 (3, 5)	6	0.78	94
5.5	2 (3)	4 (2, 3, 5)	5	0.88	98.5
6.5	2	3	5	(1)	100.5
7.5	2	3	4	(1)	101.5
8.5	2	2	4	(1)	103.5
8.5+	<2	<2	<4		>103.5

* These numbers are not shown in Figure 4.11, representing teeth which are erupted but not worn yet.

However, the statistics in Table 4.4 for sika deer of age 2.5 and above show less variation in the total score field. On the other hand, tooth wear index shows more significant difference between ages. Therefore, the age assessment of sika deer mainly relies on tooth wear.

By comparing two ageing methods we can see that each of them have advantages and shortcomings. The wear index method shows a clear pattern by reducing variation of individuals. The ageing result from a complete dentition is quite accurate, supported by a series of examinations by Koike and Ohtaishi (1985). It also tallies with the scoring scheme. Both methods are more precise to apply on younger individuals. From my own recording experience, Ohtaishi's wear index method was faster to use, and less possible to make mistakes. The discussion in the later chapters will be mainly based on the comparative results shown in Table 4.4.

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Table 4.8 Tooth eruption and replacement in mandibles of muntjac. The bracket means the tooth is erupting from crypt. From Chapman *et al* (1985).

Age (month)	Teeth
0	$i_1\ i_2\ i_3$ (c)*
1 week	$i_1\ i_2\ i_3$ c ($dp_1\ dp_2\ dp_3$)
1	$i_1\ i_2\ i_3$ c $dp_1\ dp_2\ dp_3$ (M_1)
2	$i_1\ i_2\ i_3$ c $dp_1\ dp_2\ dp_3$ (M_1)
3	$i_1\ i_2\ i_3$ c $dp_1\ dp_2\ dp_3\ M_1$
4	$i_1\ i_2\ i_3$ (C) $dp_1\ dp_2\ dp_3\ M_1$ (M_2)
9	$i_1\ i_2\ i_3$ C $dp_1\ dp_2\ dp_3\ M_1\ M_2$
12	$I_1\ i_2\ i_3$ C $dp_1\ dp_2\ dp_3\ M_1\ M_2$ (M_3)
18	$I_1\ I_2\ I_3$ C ($P_2\ P_3\ P_4$) $M_1\ M_2\ M_3$

* Refers to erupting teeth.

Table 4.9 Scoring scheme for mandibular molars of muntjacs. Reproduced from Chapman (2005).

Wear feature	Score	Max. score per tooth
Dentine exposed–cream or brown	1 per cusp	4 (+1 on hypoconulid M_3)
Buccal–lingual links	1 per link	4
Mesial–distal links	3 per link	6
Link from hypoconulid to metaconid	3	3 on M_3 only
Link from hypoconulid to hypoconid	3	3 on M_3 only
Infundibulum		
Open at one or both ends	0	0
Sealed by enamel at both ends	2	4
Reduced to ½ or less of above stage	4	8
Reduced to pin-prick or obliterated	6	12 (+ 6 on hypoconulid of M_3)
Contact enamel lost against adjacent tooth	2 per site	4 for 1st & 2nd molars, 2 for 3rd molar
Lingual cusps: loss of triangular shape, more rounded, irregular or flattened	2 per cusp	4

4.8.2.3 Muntjac

The ageing profile of muntjac was build up according to a series of research by Chapman and colleagues (1985, 2005). The tooth eruption and replacement sequence (Table 4.8) is summarized from Chapman and colleague's research (1985).

Tooth wear on the mandibles of adults were recorded in a similar scoring scheme that were used for ageing sika deer. Score of each molar is calculated following the

criteria shown in Table 4.9. The structure of the muntjac molars is simpler than other larger deer, so the scoring process appeared to be less confusing. The final scores were compared to Chapman research samples in Britain to identify the age of the archaeological specimens.

Having described the zooarchaeological methods, the next four chapter present results and discussions based on the application of this chapter.

Chapter 5 Analysis and results of fish remains

This chapter presents the original data and analytical results of the fish remains from Tianluoshan, showing the application of the methods in Chapter 4. It is broken into three sections.

The first section lists the fish species in Tianluoshan remains, and chronologically presents the statistical data of fish remains from the stratigraphic contexts following the time sequence summarized in Chapter 2, in order to evaluate the chronological change in several aspects at the same site. It also presents the reanalyzed data of H1. Besides, additional deposits samples shall be analysed, in order to adjust the bias of sampling strategy, and to discuss the taphonomic effects on fish remains.

Subsequently, the biological and ecological aspects of the predominant fish at Tianluoshan are summarized from literatures, preparing fundamental for further discussions such as species presence, palaeo-hydrographic conditions, subsistence economy, fishing strategy and other zooarchaeological issues. It also provides important information for the identification of snakeheads to species, which have been rarely studied in archaeological literatures.

In the third section, the results of applying the data processing methods in Chapter 4 shall be presented in two aspects: the body length distributions of three predominant species; and seasonality assessment from fish remains using comparative modern specimens.

Preliminary discussion is made based on these data, but the major part will be presented in the next chapters.

5.1 Range and relative proportions of taxa

An estimated total number of 430,000 fish bones from 40 contexts have been examined for this study, among which, 230,000 were retrieved from the layers and the rest from H1 the fish bone pit. 74 sub-samples have been taken from the contexts. The NISP of each species were calculated from sub-samples following the quantification method in Chapter 4, and then applied in the analysis of relative proportions. Considering the differences between stratigraphic layers and storage pit in content, formation process and property, the statistics of two groups of contexts shall be presented and discussed separately.

Table 5.1 Relative taxonomic abundance of fish at Tianluoshan by NISP and NISP %.

Taxon	Family	Stage 1		Stage 2		Stage 3	
		NISP	%	NISP	%	NISP	%
common carp *Cyprinus* sp. Linnaeus	Cyprinidae	2807	4%	5676	5%	716	6%
crucian carp *Carassius auratus* (Linnaeus)	Cyprinidae	9070	13%	38097	34%	1891	15%
top-mouth culter *Culter* sp. Basilewsky	Cyprinidae	361	0.5%	330	0.3%	37	0.3%
catfish *Silurus* sp. Linnaeus	Siluridae	2945	4%	5027	4%	747	6%
Northern snakehead *Channa argus* (Cantor)	Channidae	48581	70%	50338	45%	6477	53%
Japanese sea bass *Lateolabrax* sp.	Serranidae	308	0.4%	643	0.6%	289	2%
Unidentified		1090	7.1%	2303	11.2%	670	18.4%

5.1.1 Stratigraphic layers

As stated in Chapter 2, the strata at Tianluoshan can be generally classified into three sequential stages: Stage 1 (Layer 8 and 7), Stage 2 (Layer 6 and 5) and Stage 3 (Layer 4 and 3). Six fish of common fish have been identified from the assemblage, including common carp (*Cyprinus* sp. Linnaeus), crucian carp (*Carassius auratus* (Linnaeus)), top-mouth culter

(*Culter* sp. Basilewsky), catfish (*Silurus* sp. Linnaeus), snakehead (*Channa argus* (Cantor)), and Japanese sea bass (*Lateolabrax* sp. Cuvier). Following the methods demonstrated in Chapter 4, fish are mainly identified to the genus level, except for snakehead and crucian carp which can be identified to the species level from zoogeographical analysis (see section 5.3 in this chapter). The common carp at Tianluoshan is probably *Cyprinus carpio* Linnaeus judging from Nakajima and colleagues' (2011) identification using pharyngeal bones from Tianluoshan, and zoographic records of the Yangtze River region (Editorial Committee of Fauna of Zhejiang, 1991, Hubei Provincial Institute of Hydrobiology, 1976).

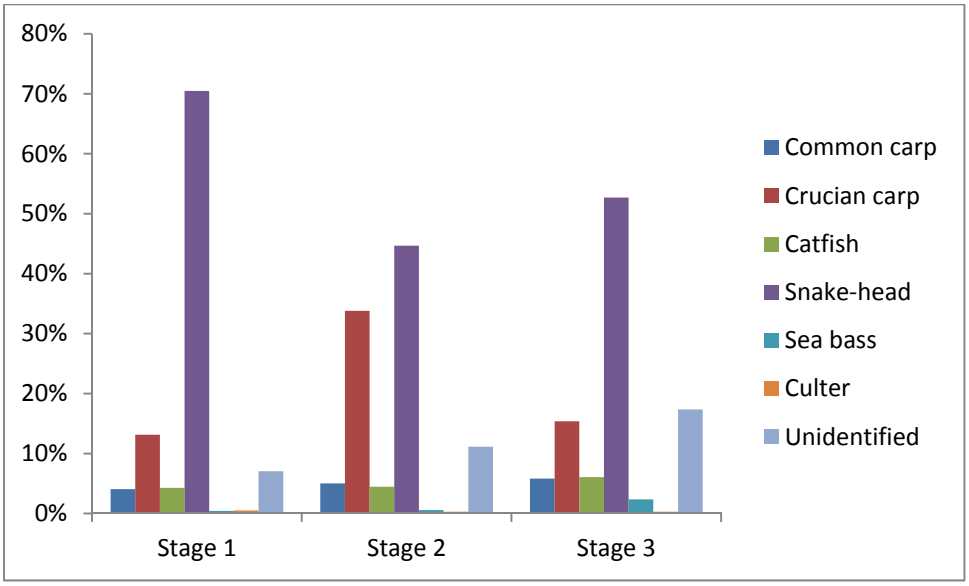


Figure 5.1 The relative proportions of the predominant fish species at Tianluoshan in sequential stages.

The NISP and relative proportions of the species in each stage are summarized in Table 5.1. These six fish take up about 90% of the total specimens. Among all the fish, snakehead shows a significant predominance throughout the stages (Figure 5.1). Its proportion in Stage 1 is up to 70%, and the number falls to around 50% in Stage 2 and 3. Crucian carp takes the second place (13 – 34%), followed by common carp and catfish with a consistent proportion around 5%. The amount of the culter fish and Japanese sea bass is relatively minor, normally less than 1%.

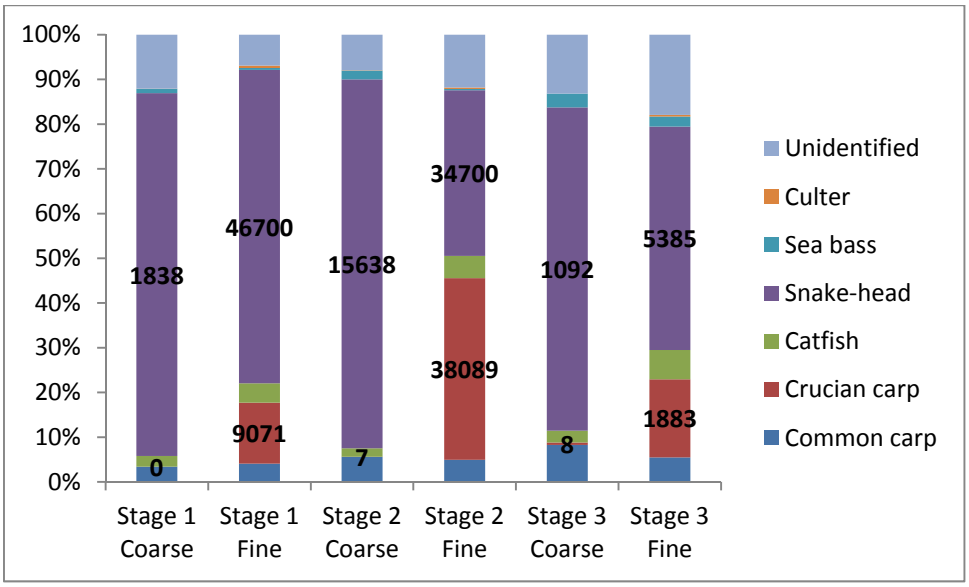


Figure 5.2 Relative proportions of fish at Tianluoshan. Coarse-sieved and fine-sieved samples from each stage are separately calculated. The NISP of snakehead (upper line) and crucian carp (lower line) are marked.

Beside of the integrated statistics in Table 5.1 and Figure 5.1, I also compare the coarse-sieved and fine-sieved samples in species presence and relative proportions (Figure 5.2). The histogram reveals significant differences between these two groups of samples. First of all, the number of specimens retrieved from fine-sieved residues is many times more than that from coarse-sieved residues. Secondly, although same species present in two groups, the relative importance of taxa differs. From the numbers in Figure 5.2 we can learn that the crucian carp are underestimated in coarse-sieved samples, possibly due to small size; meanwhile, the predominance of snakehead is overestimated. It reveals the significance of retrieving strategy to the final results, as well as the importance of fine-sieving for the study of ichthyfaunal remains.

5.1.2 H1 -- the fish bone pit

Located at the outer range of the excavation area, H1 is one of the storage pits of the early occupation stage at Tianluoshan, containing approximately 192 litres (600mm ×

800mm × 400mm) of sediments which are especially rich in fish bones (Figure 5.3 a). A few bird and reptile bones can also be found in the sediments. The content has been totally sieved and sorted into bone parts (Figure 5.3 b), and the pharyngeal teeth of cyprinids have been studied by Nakajima and colleagues (Figure 5.3 b) (2010, 2011).

Figure 5.3 H1 at excavation (a) and the retrieved fish bones which are sorted by body part (b). The first blue box in (b) contains all pharyngeal bones and teeth from H1.

Due to the huge amount of specimens, three sub-samples were taken from the sorted samples (Figure 5.3 b) for study using the sub-sampling strategy in Chapter 4. Sub-sample 1 and 2 each measures about 50 ml, and they are taken from the head bone sample which is approximately 3800 ml in total. Each sub-sample contains 1000 to 1100 specimens. Sub-sample 3 measures 200 ml, taken from the 5000 ml sample of vertebrae. Each sub-sample was sorted, identified and recorded following the procedures in Chapter 4. During quantification, both NISP and MNI were counted, and the NISP of head bones and vertebrae were calculated separately. The MNI of each fish was decided by the most elements of the species, i.e. common carp and crucian carp by pharyngeal bones, catfish by dentary, and snakehead by premaxilla.

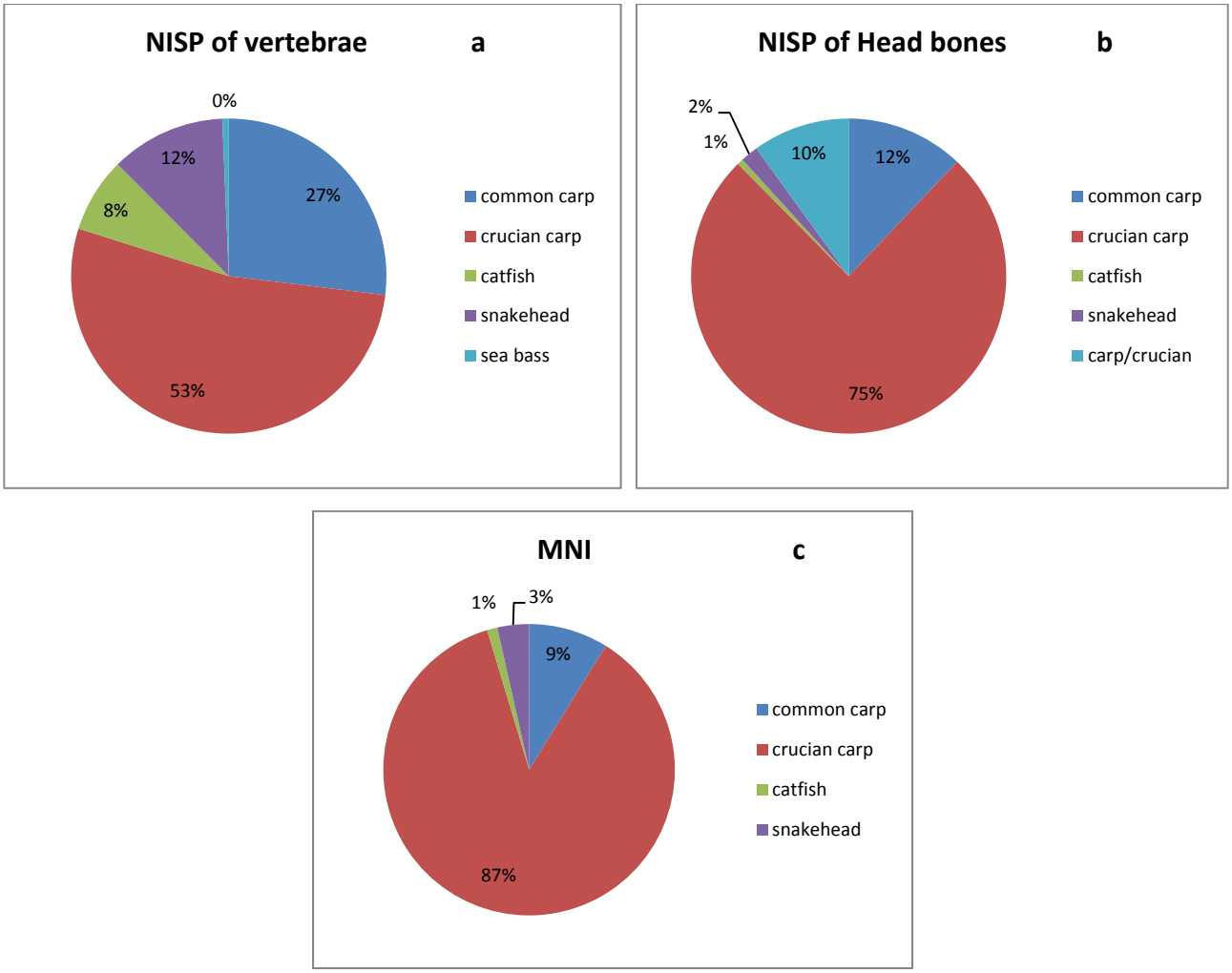


Figure 5.4 The relative proportions of taxa in H1, calculate from sub-samples which are taken from the sorted vertebrae (a), head bones (b) and teeth (c). The MNI of common carp and crucian carp were from Nakajima *et al* 2012.

Figure 5.4 shows the quantitative results of fish remains from H1 by NISP and MNI. The species in H1 remain the same as in stratigraphic layers; among them, crucian carp, common carp and snakehead are the predominant fish. Clearly, there are differences between the relative importance by NISP and MNI. For example, crucian carp takes up about half of the speciemens in the vertebrae sub-sample, but the proportions are much higher in the head bones sub-sample and in the result by MNI counted by pharyngeal teeth. On the contrary, common carp has a higher percentage in the NISP of vertebrae (27%), and a much lower percentage in MNI by pharyngeal bones (9%). Snakehead only takes a small part of both

NISP and MNI.

Generally, the composition by NISP of head bones and by MNI is similar, but both are different from that by NISP of vertebrae. The statistical difference may be caused by two reasons. First of all, the sub-samples might be biased. During the sub-sampling procedure, it was impossible to mix the whole 45,000 ml sample (including 5,300 ml vertebrae, 14,600 ml head bones and 25,000 ml ribs and other debris) evenly on the condition not to break the specimens. As a results, the NISP proportion by vertebra shows a preference for larger fish, i.e. common carp, snakeheads and catfish (Figure 5.4 a). Secondly, the results are more or less influence by identification. For example, Figure 5.4 b shows a considerate amount of cyprinid bones which cannot be identified to species. I have also found it difficult to identify a few elements to species, e.g. hyomandibular, postcleithrum. The first factor can be adjusted by taking more sub-samples. The second factor is subjective, requiring more practice and reference samples to be overcome.

Understanding the statistical errors will help to interpret the relative importance better. The diagrams indicate that cyprinids compose the main part of fish population, especially crucian carp, which takes up more than 50%. This compositional pattern shows great difference to that of layers, which on the contrary, is predominated by snakeheads. Given that the pit and stratigraphic layer formed differently, this compositional difference of fish remains is predicted. The pit was possibly formed in a short period, possibly a few weeks; while the layer was deposited through a long time, from decades to centuries, undergoing much complicated taphonomic processes.

Previous research on body length reconstruction comes to the same conclusion. The narrow distributions of common carp and crucian carp body length imply that fish of similar size, i.e. similar age, were captured. As the growth of fish is continuously linear, the result

indicates that the H1 fish assemblage was accumulated from a single fishing event rather than long termed fishing activities.

The function of H1 and the accumulation process of fish remains within have only been discussed simply previously. Nakajima and colleague made the assumption that H1 was used for processing fish such as for making fish sauce, based on the presence of various body parts of fish (Nakajima et al., 2011). The fish bone pit at Tianluoshan is not isolated. Similar features had been reported in the adjacent area, belonging to the Majiabang culture, which had a time span partly overlapped with the Hemudu culture (Luojiajiao Excavation Team, 1981). However, no residue of vessels has been detected in the pit, which should be crucial to fish processing. Comparing to all the assumptions, H1 may simply be the accumulation of the waste from fish processing or consumption. This assumption can explain the present of all skeletal parts, including head bones, pharyngeal bones, girdle bones, and all groups of vertebrae.

However, no cutting and filleting marks have been observed on the specimens. Therefore, how the thousands of fish from that catch were processed and consumed is still not clear. Considering the amount of fish from that catch, processing and storage might have been practiced.

5.2 Taphonomic issues

Considering that bias could have been made due to the problems during the retrieving procedure, seven deposit samples were taken from the 2012 excavation in order to evaluate the bone distributional density, skeletal part present, and the bias of fish remains retrieving. Restricted by the excavation process and my field work schedule, I was only able to take samples from Layer 8, 6 and 4, rather than a consistent sequence of contexts. These samples

can roughly represent three stages. Samples were taken from the pre-sieved deposits around the excavation area (Figure 5.5). Deposit sample was also taken from the content of a newly excavated fish bone pit, H65. Each deposit sample was wet-sieved through fine mesh and cool dried. Then bones were carefully picked out from the residue, sorted, identified and recorded following the normal procedure.

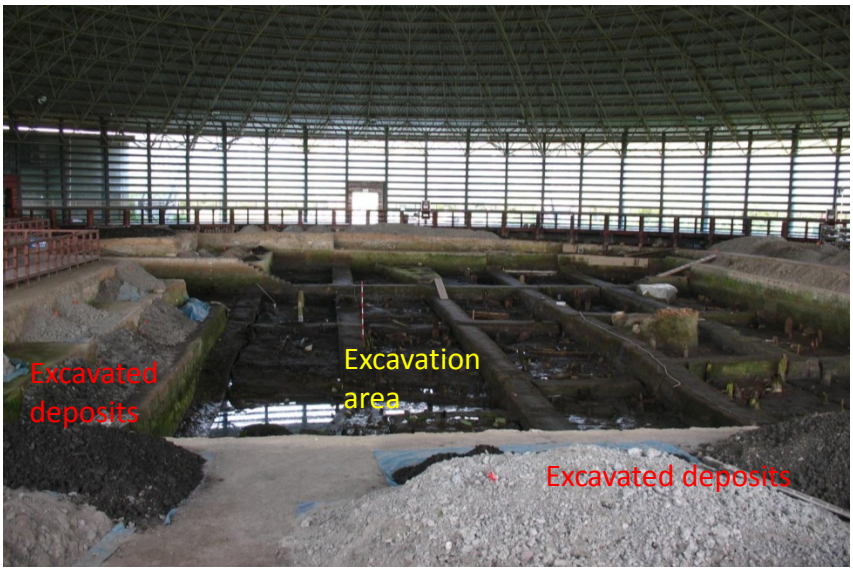


Figure 5.5 Deposits from the contexts are piled up by context around the excavation area, waiting to be sieved.

Table 5.2 Deposition samples and the number of specimens in them

Square	Layer	Volume	Fish				Tortoise	Bird	Mammal	Sum	Density /L
			Identifiable		Unidentifiable						
T303	8	2L	55	32%	110	63%	9	0	0	174	87/L
T306	8	1L	23	29%	55	71%	0	0	0	78	78/L
T107	6	3L	10	18%	45	80%	1	0	0	56	19/L
T207	6	3L	18	14%	95	72%	6	9	4	132	44/L
T207	4	5L	14	9%	123	76%	4	8	13	162	32/L
T405	4	3L	21	17%	100	81%	2	0	0	123	41/L
H65		0.8L	245			2500	0	107	0	2852	3565/L

The data of the deposit samples and bones from residues are summarized in Table 5.2. The collected bones can be roughly sorted into four groups, fish, tortoise, bird, and mammal, most of which are too fragmented to identify. The density of bones decreases from earlier

stage to latter, and so does the number of identifiable fish specimens. This can be highly related to the water-logged preservation conditions, that the fluctuation of underwater level makes the bones in upper layers weathered more heavily than those in the lower layers, which on the contrary, are constantly water-logged.

Table 5.3 The body part distributions in the deposit samples, shown by head and trunk bones.

	Common carp		Crucian carp		Catfish		Snake-head		Other		Sum		Total
	Head	Trunk	Head	Trunk	Head	Trunk	Head	Trunk	Head	Trunk	Head	Trunk	
T303-8	3	8	6	12	1	0	3	12	1	9*	14	41	55
T306-8	0	3	1	10	0	1	2	2	1	3	4	19	23
T107-6	0	3	0	0	0	1	1	4	1	0	2	8	10
T207-6	0	4	1	2	0	0	0	11	0	0	1	17	18
T207-4	1	1	0	1	0	0	1	9	0	1	2	12	14
T405-4	0	2	1	10	0	0	3	3	0	2	4	17	21
H65	16	52	11	73	11	19	7	26	0	30	45	200	245

* Including 6 scales.

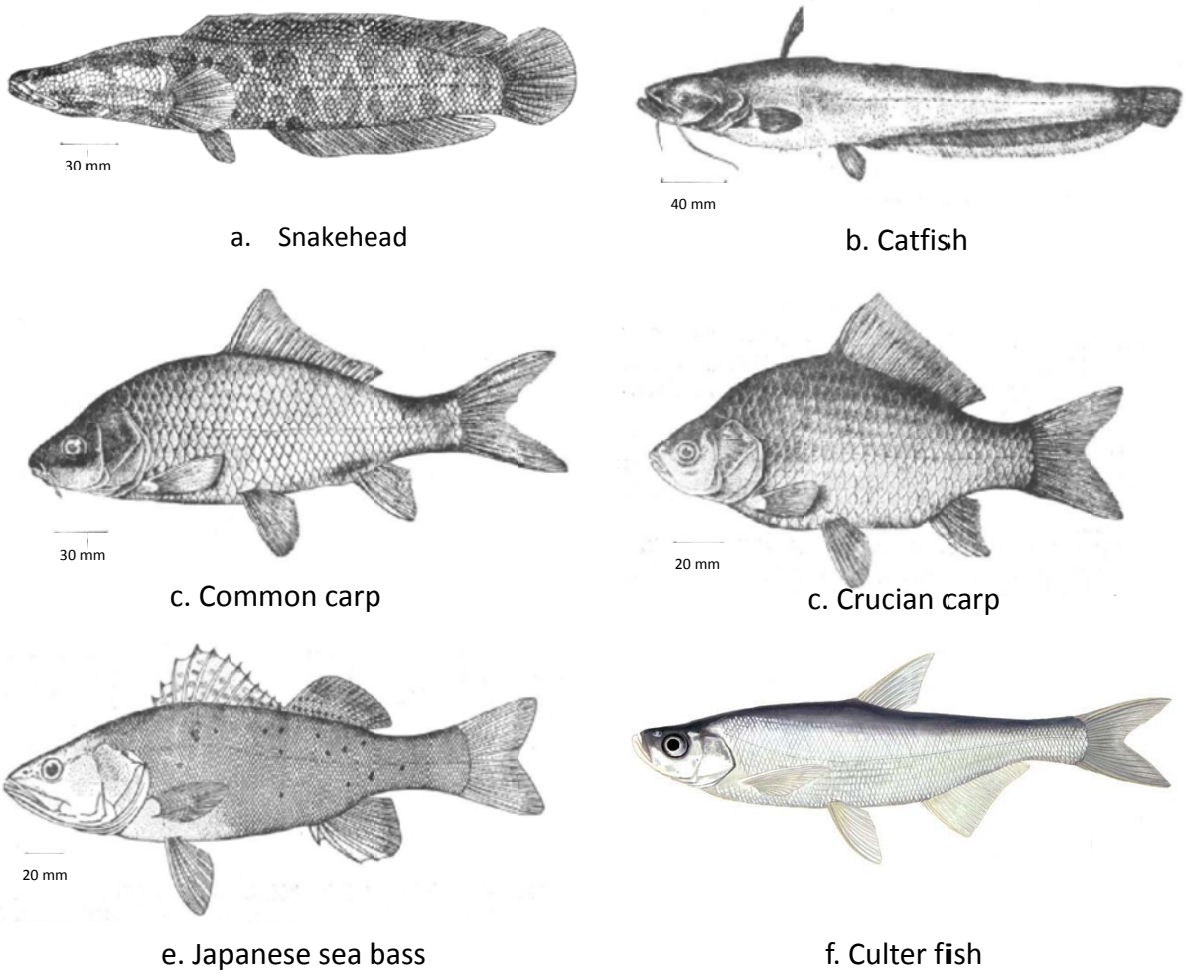
Table 5.3 shows that both head bones and trunk bones which can be identified to species are present in layers, indicating that the vertebrae-rich assemblage is caused by the problematic sampling strategy. On the other hand, the general presence of basioccipital in each sample has also proved the existence of head bones.

Although the lack of head bones brings much difficulty for the identification and further analysis, quite a few studies can be undertaken base on fish vertebrae. Plus, due to the fragility of head bones, measurement points, which are extremely important for further analysis, are more difficult to be preserved comparing to vertebrae. In this study, the analysis and discussion are mainly based on vertebrae and basioccipitals.

5.3 Modern ecology of fish and hydrographic conditions at Tianluoshan

Biological research is fundamental for zooarchaeological topics such as paleoenvironmental conditions, subsistence, and domestication (Reitz and Wing, 2008, P28-

29). The importance of knowing fish ecology and behavior during the study of fish remains has been pointed out by zooarchaeologists (Wheeler and Jones, 1989). In this section, the biological background of the six predominant fish species at Tianluoshan will be listed emphasizing these elements: 1) the modern distributional area, which may or may not be the same as archaeological records; 2) habitat, which reflects the local aqua-environment and drainage; 3) feeding habits, referring to the niche of the fish in the ecosystem; 4) reproduction, including time, location and behaviours, related to the discussion of seasonality and fishing strategies; and 5) size and life span.



a. Snakehead

b. Catfish

c. Common carp

c. Crucian carp

e. Japanese sea bass

f. Culter fish

Figure 5.6 The six predominant fish species at Tianluoshan. Figures a – e are from *Fauna of Zhejiang: Freshwater Fishes* (Editorial Committee of Fauna of Zhejiang, 1991); Figure f is from Animal Diversity Web by University of Michigan.

In general, the identified six fish species at Tianluoshan are common freshwater fish with high adaptability in the present Yangtze River region and East Asia. The farmed fish of these species are still important commercial fish in these areas. Three fish, common carp, crucian carp, and culture fish, belong to Cyprinidae, the most species-rich family of freshwater fishes and food fish (Nelson, 2006, P160). The most abundant fish in the six species will be emphasized, including snakehead, common carp, crucian carp and catfish. The ecological analysis also provides important information for the identification of snakeheads and crucian carp to species.

5.3.1 Northern snakehead (*Channa argus* (Cantor))

'Snakehead' commonly refers to the fishes of the family Channidae, which includes two genera: *Parachanna*, containing three species which are found in tropical Africa, and *Channa*, with 26 species endemic to East, Southeast and South Asia (Courtenay et al., 2004, Courtenay and Williams, 2004, Nelson, 2006; see Figure 5.6). Five species of snakeheads (*Channa*) have been found in China's territory: *Channa argus* (northern snakehead), *Channa maculata* (blotched snakehead), *Channa gachua* (dwarf snakehead), *Channa asiatica* (small/Chinese snakehead) and *Channa striata* (striped snakehead).

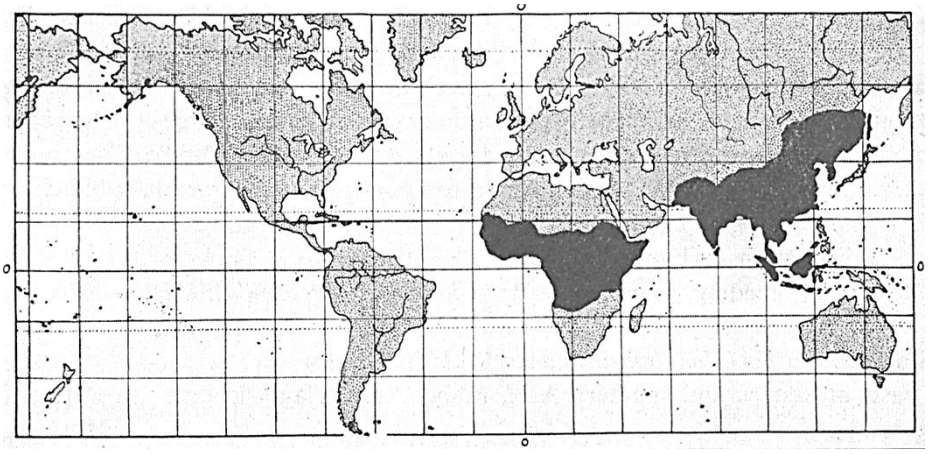


Figure 5.7 Distribution area of family Channidae (dark colour area) (Sterba, 1962, P772)

For the purpose of fish length reconstruction and seasonality assessment, the specimens should be identified to species rather than genus. Taxonomic research indicates that all species in a genus occupy a similar niche (Mayr et al., 1953, Reitz and Wing, 2008, P34). Therefore, we can assume that only one snakehead species were living around Tianluoshan. A brief review of all five species reveals that these snakeheads inhabit in similar aqua-environments, but geographically separated. For instance, two major *Channa* live in East Asia, northern snakehead and blotched snakehead, which inhabit in similar water conditions, but approximately isolated by the Nanling Mountains, the drainage divide between the Yangtze River Region and the Pearl River Region. Northern snakehead adapts to moderate to cool climate, while blotched snakehead prefers warmer climate (Chiba et al., 1989, Hubei Provincial Institute of Hydrobiology, 1976, Pearl River Fisheries Research Institute in Chinese Academy of Fisheries Science et al., 1991). Although the climate condition in Middle Holocene was probably warm enough for blotched snakehead (see Chapter 2), body length reconstruction (see below) indicates that the snakehead at Tianluoshan should be a large *Channa*, thus blotched snakehead is eliminated. Identification with reference specimens and literature also indicate that the snakehead at Tianluoshan is *Channa argus*.

Northern snakeheads (Figure 5.6a) inhabit the tranquil water bodies with muddy bottoms and plenty of aquatic vegetation, such as ponds, rice paddies and reservoirs. The ability to breathe directly from air makes them tolerance to most brutal conditions, such as hypoxic waters and dry seasons, which are fatal to most fish. As a top predator in the food chain, snakehead feed on various organisms, including zooplankton, phytoplankton, insects, small crustaceans, fish and frogs (Hubei Provincial Institute of Hydrobiology, 1976, Courtenay and Williams, 2004, Editorial Committee of Fauna of Zhejiang, 1991). This is why the introduction of snakehead has caused adverse ecological problems.

The Northern snakeheads in the Yangtze River region usually mature at the age of 2 years and length of 30 cm, and spawn in summer months, primarily from late May to July. During the spawning seasons, snakeheads perform a serial of special activities such as nest building and parenting behaviours. Nests are built in shallow waters by clearing a circular area in aquatic vegetation and creating a vertical zone of water surrounded by plants. The buoyant eggs float on the water surface, guarded by one or both parents which turn to be extraordinarily aggressive during the spawning season.

Northern snakeheads grow quite fast. Investigation shows that the average length of three year-old snakeheads is 398 mm, and the four year-old individuals can grow to over half metre (Hubei Provincial Institute of Hydrobiology, 1976, Yang, 1987). There is no detailed evidence of maximum lifespan of snakeheads, but considering its growth rate and the record of 1 metre (Novikov *et al*., 2002), it is quite possible that snakehead can live for years.

5.3.2 Common carp (*Cyprinus* sp. Linnaeus)

Common carp (Figure 5.6c) is one of the most widespread fish which has been introduced worldwide except at the poles and northern Asia. It is originally native to Europe and Asia, and is now cultivated throughout most of the world as food fish and game fish (Lammens and Hoogenboezem, 1991).

Common carps prefer warm, deep water bodies with slow flowing or standing waters, soft bottom sediments and well grown vegetation, but generally they are tolerant of a wide variety of conditions in natural and artificial reservoirs, even with low oxygen concentrations.

Carp are benthic omnivores which feed on benthic invertebrates, insects and plants (Editorial Committee of Fauna of Zhejiang, 1991). Their feeding behaviours usually cause

turbid water which is not suitable for many other fish's growth, so carp are sometimes considered as pests. Carp grow fast. Common carp in Zhejiang Province (the lower Yangtze River region) often reach 300 cm and weigh 2kg when become sexually mature (Editorial Committee of Fauna of Zhejiang, 1991). Adult carp barely have predators other than human. Fishery records show that carp can grow up to 1100 mm, weigh 40 kg, and live for 50 years (Kottelat and Freyhof, 2007).

The age of maturity varies depending on the environment, temperature and nutritional conditions. In the Yangtze River basin, carp usually mature at 2-years-old, sometimes as early as 1-year-old (Hubei Provincial Institute of Hydrobiology, 1976, Yang, 1987, Editorial Committee of Fauna of Zhejiang, 1991). The spawning season of carp in this region is generally from April to June. Adults make spawning migrations to vegetated backwaters or along shores, so that sticky eggs can attach to aqua plants and larvae can have shelter (Kottelat and Freyhof, 2007).

5.3.3 Crucian carp (*Carassius auratus* (Linnaeus))

Crucian carp (Figure 5.6d) is another widespread cyprinid in Eurasia except in a few areas such as the North Sea basin in Sweden and Norway. The cultivated crucian carp is a popular food fish in China.

There are four species of crucian carp in China: *Carassius auratus* (Linnaeus), *C. carassius* (Linnaeus), *C. auratus cuvieri* Temminck et Schlegel, and *C. auratus gibelio* (Bloch). Originally only *C. auratus* can be found in the Yangtze River region. *C. carassius* distributes in the Amur River region, and was introduced to the Yangtze River region in the 1960s; *C. auratus cuvieri* in the lower Yangtze is also an introduced fish, which originates the Biba Lake in Japan; *C. carassius* mainly distributes in Sinkiang (Northwest China) and the Middle Asia

(Editorial Committee of Fauna of Zhejiang, 1991, Li, 2013). Therefore, the crucian carp from the Neolithic sites in the lower Yangtze region could only be *Carassius auratus* (Nakajima and collecgues identified them to subspecies *C. auratus auratus*).

Crucian carp are tolerant to various water conditions, but more adaptive to backwaters with rich vegetation. They are able to survive severe conditions including low oxygen levels, high pH levels, high temperature, organic pollutants, and nearly frozen water or almost dry habitats by burying themselves in mud (Kottelat and Freyhof, 2007, P145, Hubei Provincial Institute of Hydrobiology, 1976, P128-129, Yang, 1987, P49).

Crucian carp are demersal omnivore mainly feeding on planktons, benthic invertebrates, plants materials and detritus (Kottelat and Freyhof, 2007). They are normally found about 150 mm long, but occasionally can grow to more than 500 mm after ten years' growth. According to fishery record, the crucian carp in the Yangtze River Basin reproduce for the first time at the second year after hatching (Hubei Provincial Institute of Hydrobiology, 1976, Yang, 1987, Editorial Committee of Fauna of Zhejiang, 1991). Spawning season is generally from March or April until early July, more frequently in May when the water temperature is about 20-26℃, and details may vary in different areas (Hubei Provincial Institute of Hydrobiology, 1976). Eggs are spawned in shallow waters with dense submerged vegetation.

5.3.4 Catfish (*Silurus* sp. Linnaeus)

Genus *Silurus* has several species, but only two have been found in the lower Yangtze region: *Silurus soldatovi meridionalis* Chen and *Silurus asotus* Linnaeus (Editorial Committee of Fauna of Zhejiang, 1991). A review of their habitat indicates that the catfish at Tianluoshan is probably *Silurus asotus* Linnaeus, the Amur catfish.

The Amur catfish (Figure 5.6b) are nocturnal freshwater predators which commonly

distribute in the continent East Asia and Japan archipelago. They inhabit the lower strata of lakes and rivers, and have a high tolerance for water conditions. They prey on smaller fish, invertebrates and insects.

The Amur catfish from the Yangtze River region usually spawn for the first time in the next year (April to June) after hatching (Hubei Provincial Institute of Hydrobiology, 1976). Eggs are spawned in well vegetated shallow waters or flooded lowlands. The juveniles are active predators and grow quite fast, reaching 20 cm in one year and about 40 cm in two years (Editorial Committee of Fauna of Zhejiang, 1991). The recorded maximum length of catfish in Yangtze River Valley is 82.5 cm, and in east Russia is 130 cm (Yang, 1987, Novikov et al., 2002).

5.3.5 Japanese sea bass (*Lateolabrax* sp. Cuvier)

Japanese sea bass (Figure 5.6e) is an inshore species found in coastal water, estuaries and fresh waters at the west of the Pacific Ocean, approximately from Japan to the South China Sea. The Zhoushan Islands about 60 km to the east of Tianluoshan has been one of the largest fishing grounds of Japanese sea bass. They are also commonly found in the estuary of Yangtze River and tributaries, sometimes downstream rivers.

Japanese sea bass are predaceous fish which feed zooplankton at an early age and on fish and shrimps as adults. Juveniles become mature at age two. Adults are catadromous, returning to sea to spawn in deeper rocky reefs or inshore areas, and juveniles ascend rivers to brackish or fresh water. In the East Sea, spawning usually occurs during early spring (Editorial Committee of Fauna of Zhejiang, 1991). The juveniles grow fast, usually to about 30 cm at age one, and 42 cm at age two, according to the records of Japanese sea bass in the Yangtze River region (Hubei Provincial Institute of Hydrobiology, 1976). They may grow up to

100 cm.

5.3.6 Culter fish (*Culter* sp. Basilewsky)

Culter fish, also known as top-mouth culter fish (Figure 5.6f), is a freshwater cyprinid living in the temperate zone of Europe and Asia. They usually inhabit rivers and floodplain lakes with aquatic macrophytes. Culter fish are benthopelagic fish, living and feeding near the bottom as well as in midwater and near the surface.

The study on culter fish is not as much as on the other five fish species above, so the information about its behaviours is limited.

To sum up, the predominant fish at Tianluoshan share a few common features, indicating the aqua-environmental conditions of the fishing field, and an intentional selection of fish species. These are all widespread, fast growing, reproductive and tasty freshwater species, and still very important commercial fish in the Lower Yangtze River Region. In order to raise the yield, the fishes have been farmed for decades or even centuries, showing their importance in subsistence economy. Apart from Japanese sea bass, the other five species share a similar habitat environment, i.e. the rich vegetated brackish water bodies, which is possibly the primary fishing ground. This conclusion from ecological analysis is in accordance with the results from previous palaeo-environmental studies (see Chapter 2). Further discussion about the interrelationship between fishing activities and the environment will be included in the following chapters.

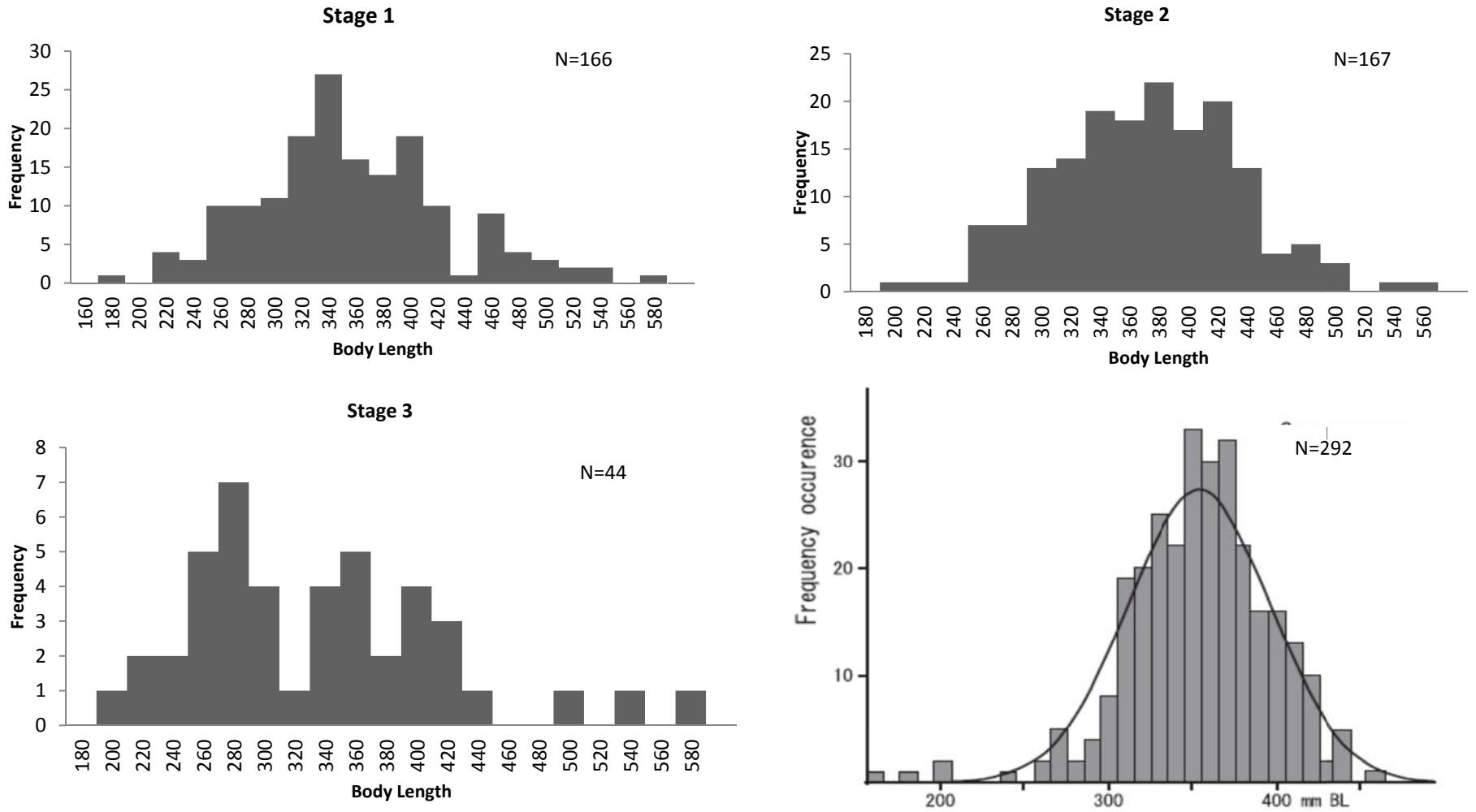


Figure 5.8 The body length distribution of common carp at Tianluoshan in Stage 1 – 3 and fish bone pit H1. The distribution of common carp in H1 is reproduced from Nakajima *et al* 2012.

5.4 Body length reconstruction and seasonality

The reconstruction of body length is only practiced on the three predominant fish from Tianluoshan, including snakehead, common carp, and crucian carp. The lengths are all estimated using modern reference samples. The methods for this part study have been introduced in Chapter 4.

For common carp and crucian carp, the correspondence equations have been established by Nakajima and colleagues (Nakajima et al., 2010a, 2011). This study will continue those data, to expand the analysis on the fish bones from H1 to the total site. For snakeheads, modern specimens are especially collected from the middle Yangtze River region with the help of IHB (Institute of Hydrobiology, Chinese Academy of Sciences) in China. The body lengths reconstruction of three fish species shall be presented in order in this section.

5.4.1 Common carp

The body length distribution of common carp is derived using Nakajima's formula correlating body length and the size of pharyngeal tooth A2. Unlike Nakajima's study, I only took the pharyngeal tooth from one side for measurement and body length estimation, to avoid double count of the same individual. Thus, the sum of frequency equals the MNI in each stage. Figure 5.8 shows the frequency distribution by every 20 mm.

Generally, the body length distribution of common carp from each layer is shown as a single peak spanning a wide range approximately from 150 mm to 600 mm. According to literatures, fish in this range are from one to five years old. From the histograms we can learn that the distributional pattern shifts from stage 1 to stage 3, and the variations can be indicated by the statistics in Table 5.4. The difference between stages and pit H1 is greater.

The distribution of common carp from H1 is more concentrated at the length span of 300 mm to 450 mm, while in the layers this range is wider, represented by a concentrated block at Stage 2.

Table 5.4 Comparative statistical summary of derived body length distribution of common carp from three stages and H1 at Tianluoshan.

	Sample size	Mean (mm)	Median (mm)	Minimum (mm)	Maximum (mm)	Skew	Kurtosis
Stage 1	166	348.2	339.2	176.6	567.8	0.95	0.46
Stage 2	167	360.7	364.1	193.4	559.0	0.55	-1.34
Stage 3	44	323.8	321.5	189.3	560.7	1.14	0.06
H1	292	353.6	355.7	163.6	457.1	-0.79	2.37

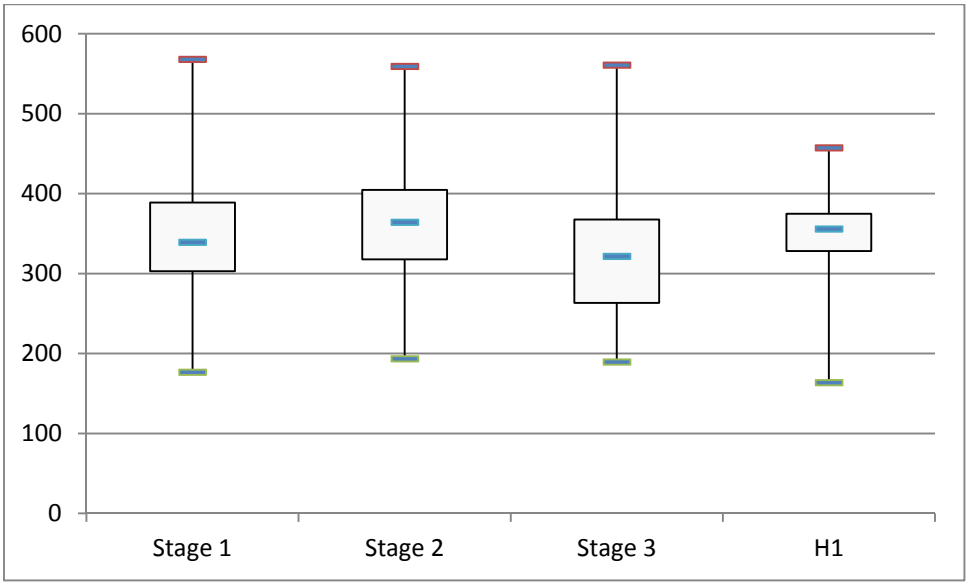


Figure 5.9 The range of distribution of common carp from three stages and H1 at Tianluoshan

The histograms in Figure 5.8 and statistics in Table 5.4 show fluctuation in body length through time, and a great decline in Stage 3. The distribution of Stage 3 reveals three small peaks at 240 mm – 300 mm, 320 mm – 360 mm, and 380 mm -420 mm, which is possibly related to fishing scheduling and strategies. This characteristic will be investigated further in

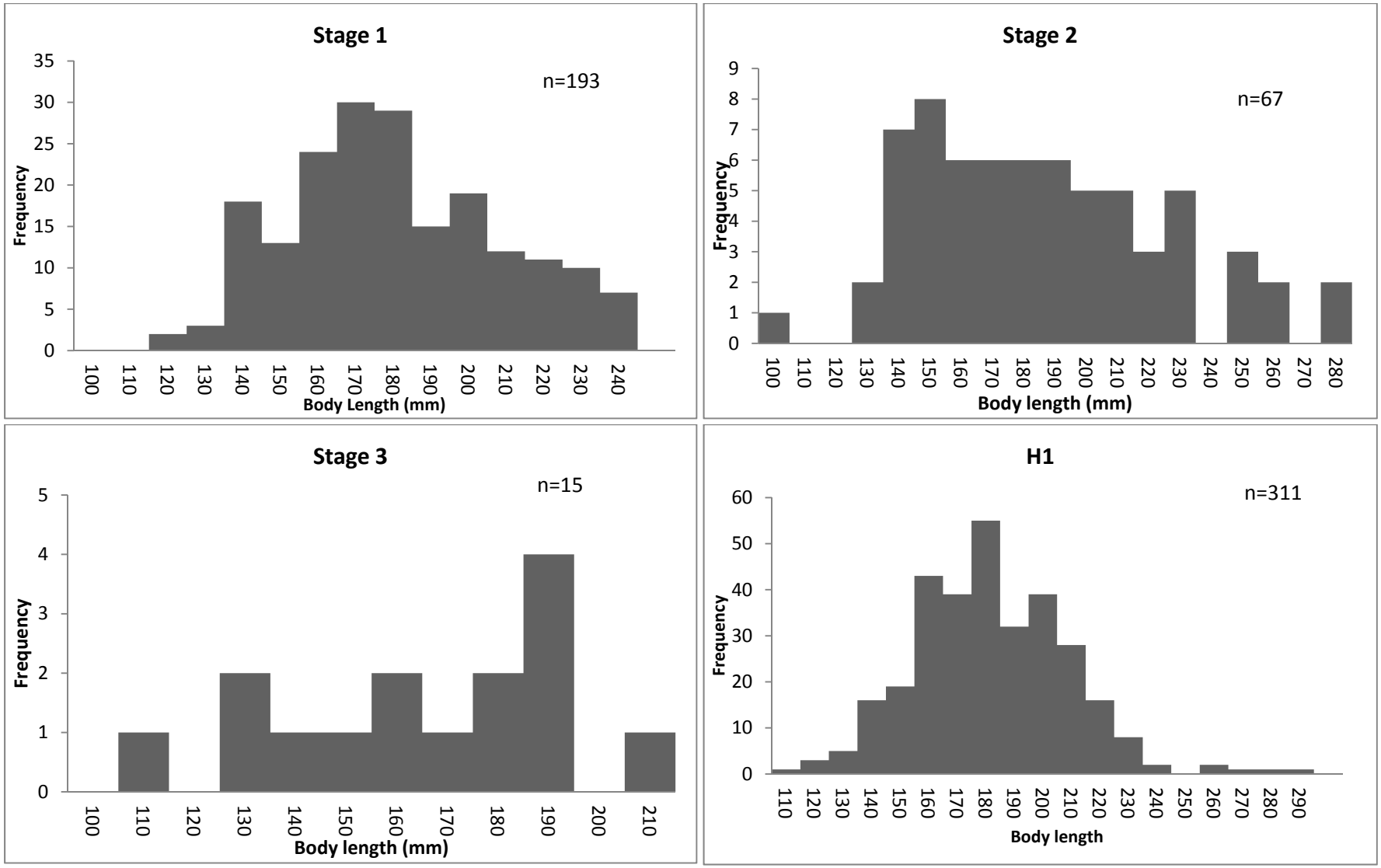


Figure 5.10 The body length distributions of crucian carp in stages and H1 at Tianluoshan, reconstructed from the length of second vertebra.

the next chapter.

5.4.2 Crucian carp

The body length of crucian carp is estimated from centrum length of the second vertebra, using the single regression equation in Chapter 4, and the distributions are shown in Figure 5.10 by stage.

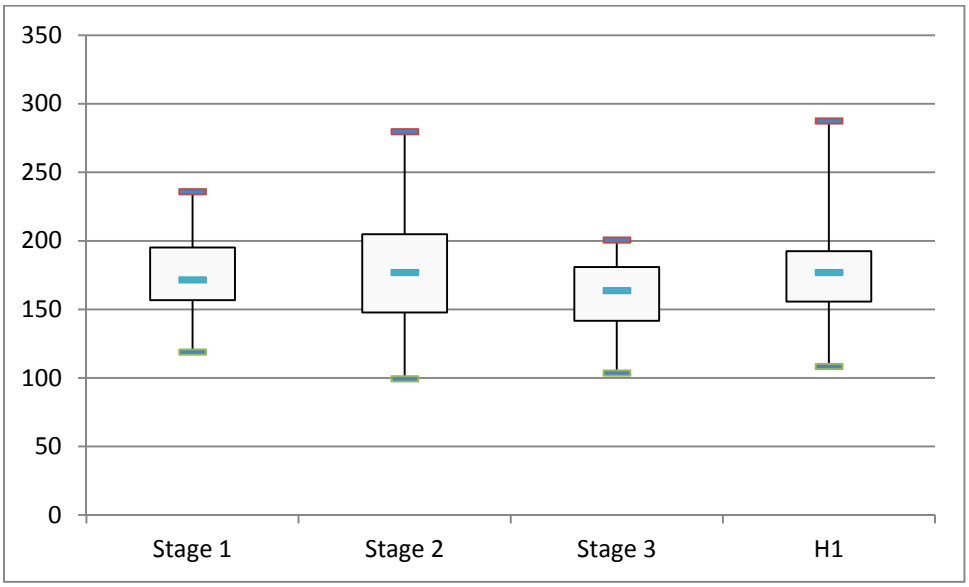


Figure 5.11 Distributional range of crucian carp from Tianluoshan, in three stages and H1.

The histograms show a wide body length distribution range for crucian carp, especially those individuals larger than 130 mm, indicating a year-round fishing strategy, and possibly an intentional selection of larger fish. However, there are also fluctuations in each stage. For example in Stage 1, the distribution peaks at 160 mm; and two small peaks appear at 140 mm and 200 mm. It possibly refers to periodic fishing seasons, which repeated annually. The distributions at Stage 2 and Stage 3 are simpler, due to smaller sample size. Figure 5.11 shows a relatively stable trend of fish size through the stages, as well as in H1 the fish bone pit. The estimated body length of crucian carp provides information for the discussion of fishing strategies in the next chapter.

5.4.3 Snakehead

The body length and culling season of the snakeheads from Tianluoshan are estimated using modern reference specimens (Chapter 4). The relative methods have been explained in previous chapters, and the data are listed in Table 4.5. The correspondence between the width of basioccipital (WB) and body length (BL) can be expressed by an equation:

$$\mathrm{BL} = 59.17 \times \mathrm{W}B - 47.01$$

With the measurements of archaeological specimens, the body length of each basioccipital is estimated. The histograms in Figure 5.13 show the distributions of snakehead body lengths in each stage as well as in H1. Hundreds of basioccipitals have been measured in each stage, but there are only a few specimens in H1.

An extremely wide range of snakehead body length has been detected in each stage, according to the reconstruction, from 140 mm to 900 mm. As with carp, snakeheads within a certain size range are preferred, generally from 200 mm to 450 mm, although the exact size varies slightly between stages. However, only very large snakeheads, ranging 370 mm to 740 mm, are captured in the H1 catch.

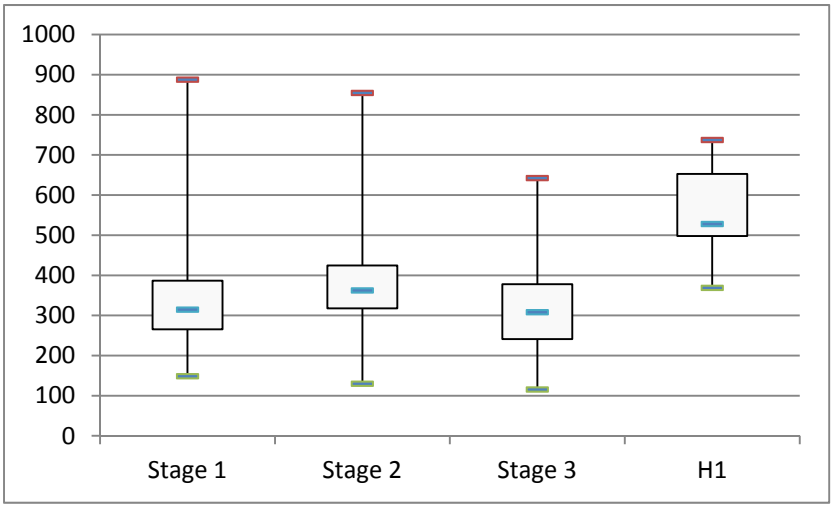


Figure 5.12 Distributional range of snakehead from Tianluoshan, in three stages and H1.

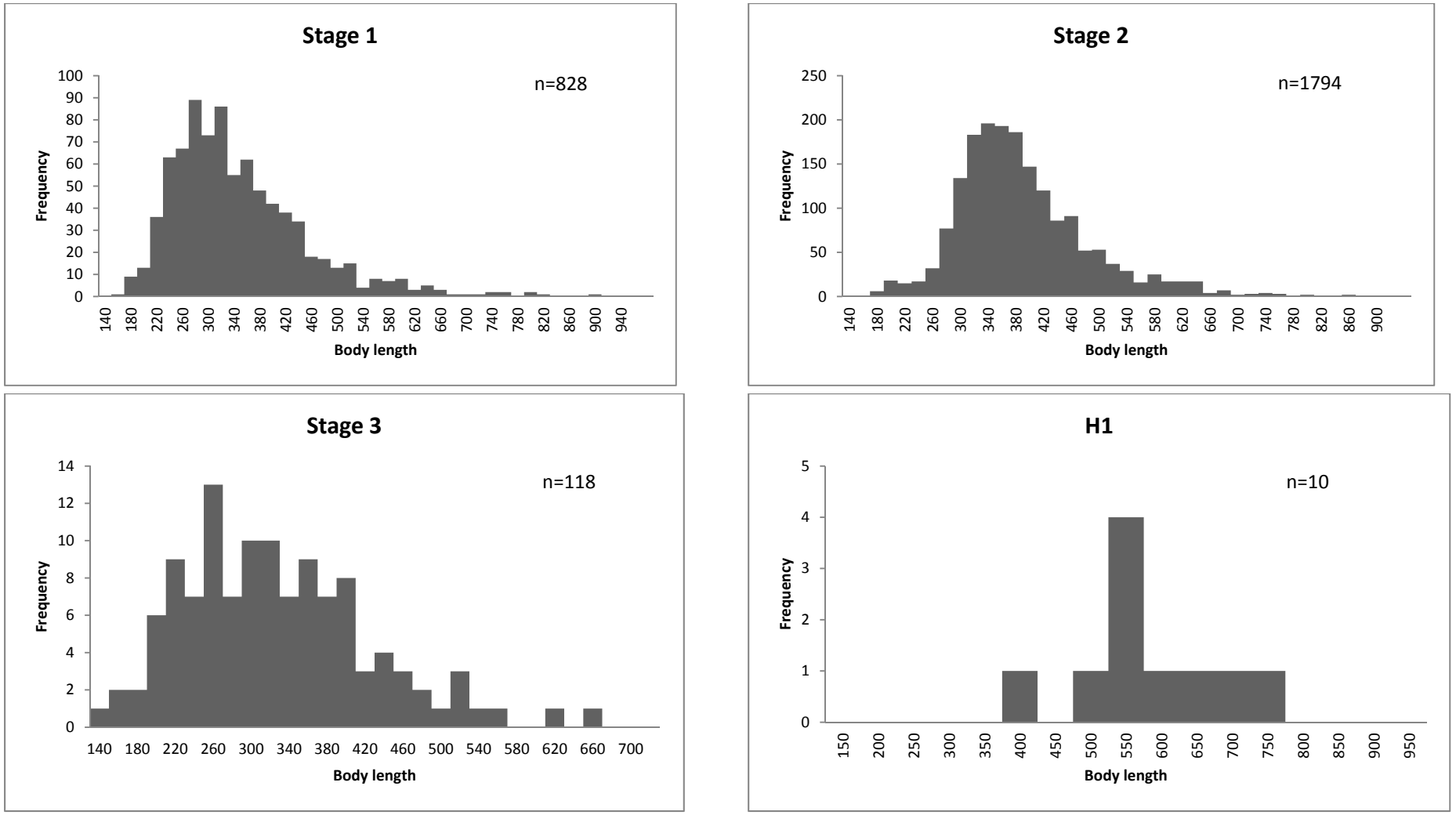


Figure 5.13 The body length distributions of snakehead in three stages and H1 at Tianluoshan, reconstructed from the width of basioccipital.

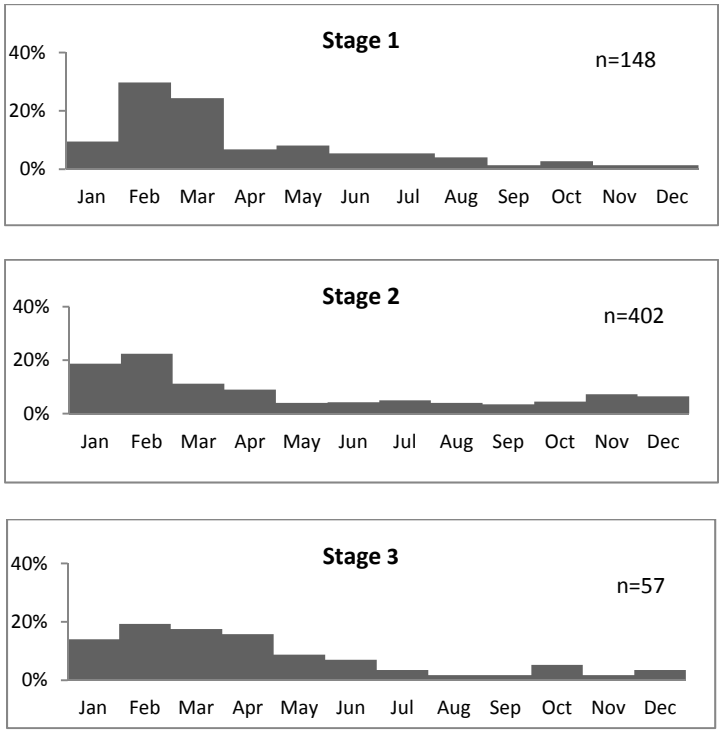


Figure 5.14 Seasonality of fishing at Tianluoshan, estimated from snakehead basioccipitals.

5.5 Seasonality

According to Nakajima and colleagues' research, the common carp and crucian carp from H1 are captured in spring to early summer, judging from the estimated size of fish (Nakajima et al., 2010a, 2011). In this section, the fish remains from layers, especially snakehead remains, shall be studied to investigate the fishing seasons Tianluoshan. A different method shall be employed, that seasonality is determined through the growth rings. Comparing to H1, the seasonality analysis may suggest several seasons rather than a single season.

The basioccipitals of snakehead are used for estimating the fishing seasons at Tianluoshan. The general idea of the method is to compare the growth ring patterns of archaeological specimens to modern samples. The modern reference specimens of different age are collected by month, in order to find out at what time of year do

growth rings form, and to reveal a sequence of growth ring formation. Usually it requires at least a year to collect and prepare the reference samples. However restricted by time and budget, the reference sample only includes 22 individuals collected from January to August.

Observation on the modern specimens indicates that a growth ring mostly completes in spring, varied by individual from February to May. However, the difference between individuals may have raised the error of seasonality estimation. Judging from this modern sample, most growth rings complete in February.

However, the annuli on two sets of specimens are quite different. On the modern specimens, the fast and slow grown part of the annulus are presented as transparent and opaque rings, but on archaeological specimens they can only be identified by colour and grooves on the articulation surface. The estimation mostly depends on the outermost circle of the annuli, therefore, the observation is easily affected by taphonomic factors.

The estimated fishing months are shown in Figure 5.14. The distributions in three stages all suggest that snakeheads are captured throughout the year, but more concentrated in spring. Plus, the fishing season tends to expand from Stage 1 to Stage 3, possibly indicating that people rely more on fishing in the Tianluoshan subsistence economy in the late Hemudu period. The chronological change shall be discussed further in Chapter 8, integrated with the study results with mammalian remains and plant remains.

5.6 Conclusion

Summarizing from the statistical data above, the ichthyfaunal assemblage at Tianluoshan is mainly made up of six species; from the most abundant to the least, they are: snakehead, crucian carp, common carp, catfish, culter fish, and Japanese sea bass. The fish remains in layers, which are classified into three stages, are mainly predominated by snakehead, with a proportion up to 70% by NISP. Crucian carp is the second most common fish by NISP in the stages. However, the fish assemblage retrieved from H1, the fish bone pit, is dominated by crucian carp, and snakehead is minute. The compositional difference is possibly caused by distinctive taphonomic processes.

Taphonomic effects on the preservation of fish bones are also examined, by processing deposits sampled strictly following the steps. The examination reveals that both head and trunk bones exist in contexts, but the retrieval procedure overlooked head bones. Besides, bones in lower stages were preserved better than upper layers.

A brief review of the biology and ecology of the six predominant fish indicate reveals that they were captured from same body of water, i.e. the rich vegetated wetlands near Tianluoshan, except for Japanese sea bass, which was possibly from an estuary environment. With the information, I was able to identify the *Channa* specimens to species, mainly based on physical feature (e.g. body size) and habitats.

The body length distributions of fish are established in order to view the body size preference of fishing during difference time at Tianluoshan, and prepare data for further discussions on fishing methods and scheduling. As Tianluoshan was a settlement site which had been occupied for two millennia, it is understandable that

fish of varied size were captured for consumption.

Seasonality analysis has suggested the same assumption, that the fishing events might happen throughout the year, indicating that fishing was routine in the subsistence economy. However, the fishing activities at Tianluoshan were much more active during spring, and possibly lasted until early summer in late Hemudu period (Stage 3). The interpretation of fish size selection and seasonal scheduling shall be pursued in next chapter.

Chapter 6 Discussion of fish remains and fishing strategy

Based on the data presented and analysed in Chapter 5, the following questions are raised: 1) why were these fish species chosen by the Tianluoshan people instead of others; 2) how were the relative proportions of fish assemblage formed; 3) what were the fishing strategies at Tianluoshan, including fishing tool, fishing methods, etc.; 4) were the fishing events at Tianluoshan seasonal or year-round activities? Analysis and discussion across different disciplines shall be included in this chapter to pursue the answers, including environmental studies, ichthyology, and ethnography.

There will be four sections in this chapter. The first section aims to answer the first two questions, about fish species and relative proportions. Subsequently there will be discussion on fishing strategies, based on environmental, zooarchaeological, archaeological and ethnographic analysis. In the third section, the seasonality of fishing is inferred using ichthyologic methods which have been reviewed in Chapter 3. In the last section, all the analyses in the previous three sections shall be integrated together in order to discuss the exploitation of aquatic resources at Tianluoshan.

6.1 Fishing and the environment at Tianluoshan

Chapter 5 presents the taxonomic range and relative proportions of the fish assemblage at Tianluoshan. It shows that the assemblages of the three stages consist of a limited number of fish species. Among all the fish species, snakehead makes up the largest proportion in the assemblages, generally more than 50%, and crucian

carp comes the second. The results indicate that the Tianluoshan people mainly lived on a predatory fish rather than herbivorous fish. As we all know that ichthyophagous fish are at the top or the food chain in the aqua ecosystem, normally in the aqua environment, carnivorous fish should be much less than herbivorous fish. Plus, according to the ecosystem principle, it would be more efficient to live on herbivorous animals.

In this section, I will attempt to investigate the predominance of snakehead from three perspectives: 1) taphonomy, which is greatly relevant to the preservation and survivorship of the fish remains; 2) environment, which decides the originally fish population at Tianluoshan; and 3) selection by fishing strategies. The discussion will focus on the natural factors and principles rather than archaeological materials, in order to investigate the interpretations and possibilities thoroughly from the study objects themselves, before proceeding to the archaeological materials.

6.1.1 Taphonomic factors

Data in Chapter 5 have presented the compositional difference between stratigraphic layers and H1 the fish bone pit. H1 is mainly filled with crucian carp bones, with a high MNI proportion at 87%, distinctive from the layers. One consideration is that H1 represents a fishing event or a fishing season, while the fish remains from stratigraphic layers are the sum of the fishing activities during the whole occupation of the site. Another factor is that H1 is extremely well preserved and that all skeletal parts were collected, including ribs which are hardly preserved in stratigraphic layers.

The conflict between two groups of fish remains indicates that taphonomic

issues may have played an important part in the predominance of snakehead.

First of all, the survivorship of different fish bones varies due to their natural features. Crucian carp are small fish which are usually found about 15 cm long, while snakeheads are medium to large fish which can grow fast to a large size. By comparing the specimens of both fish, the skeletal parts of crucian carp are much smaller and more delicate, while the bones of snakeheads are larger and robust. The diameter of the articulation surface of largest basioccipital of snakehead is 15.8mm, representing an individual approximately 90 cm long according to the body length reconstruction formula. Therefore, snakehead remains are more likely to be preserved.

In addition, smaller bones like crucian carp can be easily overlooked during the retrieval process, as it is practiced by the untrained workers (details in Chapter 4). On the other hand, snakehead vertebrae, which are larger, are collected without being overlooked so much. The new sieving programme of samples from layers shows that the density of smaller fish such as crucian carp is slightly underestimated, but it does not change the result that snakehead makes up the largest proportion in the assemblage.

6.1.2 Environmental factors

Apart from the taphonomic issues, environmental factors might be a factor in the predominance of snakeheads. The investigation starts from answering a simple question: is it possible that there were more snakeheads in the environment near Tianluoshan than carp, so that the composition of the fish assemblage is directly caused by the original fish availability?

The integrated environmental research at Tianluoshan has shown that the site was located near a considerable area of wetlands, which was an important food resources catchment (Fuller et al., 2011, Zheng et al., 2011, Kanehara and Zheng, 2011), and also the probable catchment for fishing. Therefore, wetland is the basic and important factor in the species diversity and composition of fish populations.

From the perspective of ecology, wetlands can be defined as an ecosystem that arises when inundation by water produces soils dominated by anaerobic processes and forces the biota, particularly rooted plants, to exhibit adaptation to tolerate flooding (Keddy, 2000). Although it has been commonly understood that wetlands play an important part in global ecosystems, the ecology of wetland animals has received much less research attention than the ecology of terrestrial, aquatic, or marine animals (Batzer et al., 2006).

Wetlands share common features with both aquatic and terrestrial systems. Nevertheless, there are two features that together make wetlands unique: anaerobic soils and water, and the distinguishing macrophytes (van der Valk A. G., 2006, P3). Anaerobic soils and water is the basic characteristic of wetlands, and should be responsible for the corresponding adaption of wetland plants and animals. Wetland plants and animals have developed a series of features to survive in the severe oxygen-deficient environment, such as the gas-space continuum from leaves to roots in herbaceous macrophytes to overcome the anaerobic soil, and the ability of a few fish to breathe directly from the air.

As with other aquatic organisms, the distribution of fish is controlled by factors including oxygen levels, water depth, water chemistry, and water temperatures (Mathews, 1998). Generally, fish species are not unique to wetlands and are also

found in adjacent lakes and streams. However, due to the anaerobic water and the periodic dry season (with no or very shallow standing water), fish may be absent from some kinds of wetlands. If not, their number and diversity are expected to be much lower compared to fish in other aquatic ecosystems, e.g. riverine and oceanic fish. Wetlands which are connected to other water bodies can support more fish because the fish can escape to the refuge during dry seasons.

Fish which succeed to survive in wetlands usually have developed some simple but effective methods to overcome the problems. A significant group of the wetland fish members is the air-breathing fish, which have developed a variety of specialized organs that allow them to gulp air at the surface of water, such as catfish, lungfish and snakeheads. The low oxygen levels also limit the reproductive and hatching success of fish. Accordingly, many fish spawn buoyant eggs with an oil droplet in the yolk mass so that they can float on the surface of water to obtain enough oxygen. Fish like snakehead also perform parenting behaviours for guarding their larvae, by swimming around them or nursing them in their mouths, which can efficiently increase the larvaes' survivorship rate.

The method of overcoming dry season problems is to hide or escape during that time of year. Air-breathing fish, such as lungfish, often survive the dry season (when wetlands can go completely dry) in mud in a hypometabolic aestivating state, reducing their oxygen consumption, dropping their heart rate and lowering their blood pressure (van der Valk A. G., 2006, P79). Fish which do not hibernate may swim to adjacent water bodies before the wetland dries up. Some air-breathing fish like snakeheads can even crawl overland as long as their skin keeps moist, usually in mud.

Another group of common fish in the wetland ecosystem is the cyprinid, which

prefers tranquil waters, and these include common carp and crucian carp. They manage to survive the anoxic conditions in several ways, such as by swimming to the water's surface to ventilate their gills in the thin layer of oxygenated water adjacent to the air-water interface, or by moving to areas with oxygen (van der Valk, 2006, P78). The migration towards oxygen can be seasonal or daily: by day they shelter and feed in wetlands; by night when oxygen level drops they move back to lakes. Seasonal migration to the wetlands can occur for another important reason. Wetlands, especially those associated with lakes, play an important part as spawning fields and as refuges for some fish species. Both the upstanding and submerged plants provide protection for both juveniles and adults.

Figure 6.1 River system and drainage in the Lower Yangtze River region

The analysis of the wetland ecology explains the existence of the fish species at Tianluoshan, and the simplicity of the fish assemblage composition. Unfortunately, there is no record of the exact proportions of each fish species in wetland fish populations. It can be inferred that the proportion of air-breathing fish, which are ichthyophagous, is higher than that in other water bodies such as rivers and lakes, where the fish diversity is much higher. Taking the fish composition in Taihu Lake

(Figure 6.1) for example, records indicating that most fish are cyprinids; the proportion of snakehead is very low (Qin, 2008, P276-277). Therefore, by comparing the fish community in common freshwater bodies, the proportion of snakehead in wetlands may have been raised due to the limitations of the environment.

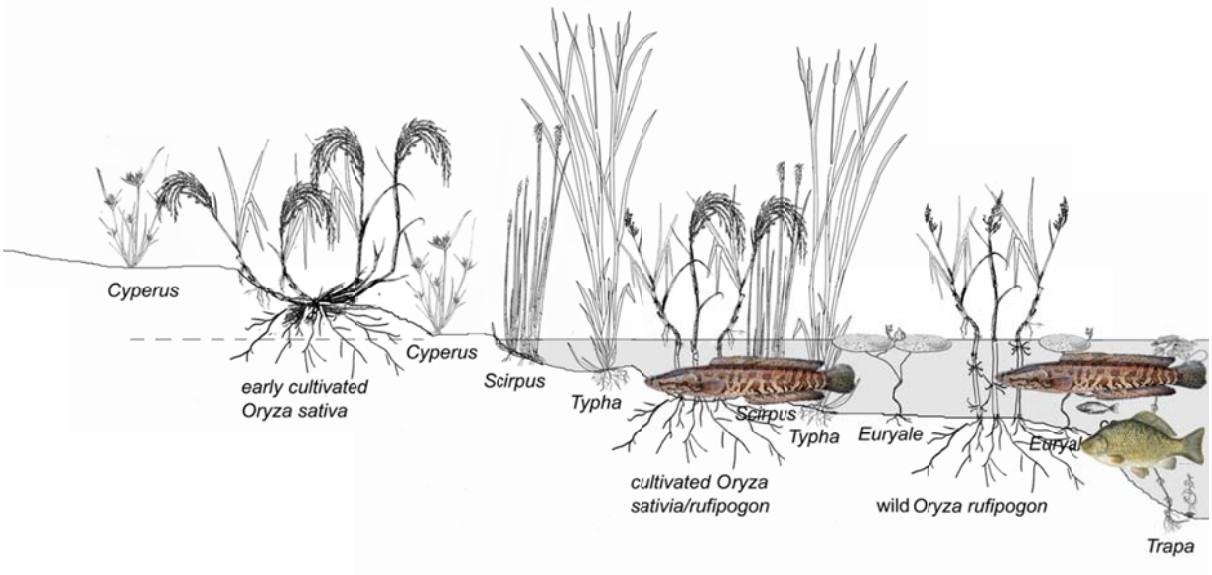


Figure 6.2 Reconstruction of the spacial distribution of fish in the wetlands environment at Tianluoshan.

Also, the habit distribution of snakeheads may have encouraged the possibility of being captured. Judging from their biological and ecological features, snakeheads can survive even more severe environmental conditions than cyprinids. Therefore spatially, the distribution of snakeheads might be expected throughout wetlands, while carp may be less and found fringing wetland environments (Figure 6.2). Apparently the wetland fringes would have been closer to the Tianluoshan settlement, according to reconstructions, and the shallow water may have made it easy to trap or catching fish with bare hands. Under these circumstances, fishing tools and fishing methods should also be considered.

Table 6.1 The potential food fish in the lower Yangtze basin, featuring their size, natural habitat, economic significance, and the estimated possibility to be recovered at Tianluoshan. The data are summarized mainly from *Fauna of Zhejiang: Freshwater Fishes* (Editorial Committee of Fauna of Zhejiang, 1991) and *Fishes of the Taihu Lake*(Ni and Zhu, 2005) which have a full list of the fish in this region and evaluation of the importance of each fish. The economic significance is evaluated on a scale '1' to '5': '1' refers to little significance, and '5' refers to great importance in fishery. Whether a fish presents at Tianluoshan is estimated from its habitat.

Fish	**Size**	**Habitat**	**Economic significance**	**Whether available at Tianluoshan**	**Recovery**
Acipenser sinensis Gray	630 mm	Anadromous fish; can be found in the Yangtze River and the East Sea.	1 Rarely found.	Less possible	Only scute
Psephurus gladius Martens	785 mm	Anadromous fish; can be found in the Yangtze River and the near seas.	1 Rarely found.	Less possible	Only scute
Macrura reeversii (Richardson)	Approx. 300 mm	Anadromous fish.	4 Precious food fish. Fishing usually occurs at spawning season (April to June).	Possible	Skeletal parts
Coilia ectenes Jordan et Seale	200-300 mm	Anadromous fish.	4 Fishing season: April, May, and June.	Possible	Skeletal parts
Coilia brachygnathus Kreyenberg et Pappenheim	124-188 mm	Middle and lower reaches of rivers and lakes; prefer turbid waters.	3 Small food fish.	No	None

Plecoglossus altivelis Temminck et Schlegel	150-200 mm	Catadromous. Short drainage system.	3 Small food fish.	Less possible	Hardly
Protosalanx hyalocranius (Abbott)	150 mm	Upper level of brackish water and freshwater.	3	Possible	Hardly
Neosalanx tangkankeii taihuensis Chen	42-63 mm	Upper and middle layers of freshwater.	3 Small but breed fast and widely distribute.	Possible	Hardly
Salanx ariakensis Kishinouye	90-112 mm	Upper and middle layers of brackish water.	2	Possible	Hardly
Anguilla japonica Temminck et Schlegel	211-354 mm	Catadromous. Middle and lower levels of water. Nocturnal.	5 Wide distribution.	Possible	Skeletal parts
Anguilla marmorala Quoy et Gaimard	331-615 mm. Can grow to over 30 kg	Catadromous. Middle and lower reaches and branches.	4 Food fish, but low quantity	No	None
Mylopharyngodon piceus (Richardson)	120-850 mm, up to 60 kg.	Lower level of large water bodies e.g. rivers and lakes	5	Less possible	Skeletal parts if fish consumed at site.
Ctenopharyngodon idellus (Cuvier et Valencinnes)	Can grow to over 35 kg.	Lower level of wide and still water bodies. Feed on water plants.	5 Grow fast and wide distributed	Less possible	Skeletal parts if fish consumed at site.
Elopichthys bambusa (Richardson)	Up to 50 kg.	Upper level of wide water bodies e.g. rivers and lakes	4 Grow fast	Less possible	Skeletal parts if fish consumed at site.
Opsariichthys uncirostris bidens Günther	149-182 mm	Tributaries of the upper and middle reaches.	3	No	None

Squaliobarbus curriculus (Richardson)	273-305 mm	Large water bodies of middle and lower reaches	4	Possible	Skeletal parts
Hemiculter leucisculus (Basilewsky)	100-140 mm, up to 200 mm.	Upper level of both running and still water.	3	Possible	May not recovered due to small size.
Culter erythropterus Basilewsky	100-200 mm, up to 300 mm	Sluggish and plant-rich area in lakes and rivers. Move to deep water in winter.	2	Possible	Skeletal parts
Parabramis pekinensis (Basilewsky)	179-278 mm	Middle and lower level of both sluggish and running waters. Spawning only occurs in running water. Move to deep water in winter.	4	Possible	Skeletal parts
Pseudolaubuca sinensis Bleeker	100-200 mm, up to 260 mm	Sluggish and running freshwater. Usually swim swiftly in shallow water. Survive the winter in deep water.	3	Possible	Skeletal parts
Megalobrama amblycephala Yih	230-500 mm, up to 3 kg	Middle and lower level of sluggish open water, e.g. rivers and lakes.	5	Very possible	Skeletal parts
Megalobrama terminalis (Richardson)	154-457 mm	Middle and lower level of sluggish open water, e.g. rivers and lakes.	4	Very possible	Skeletal parts

Erythroculter ilishaeformis (Bleeker)	2kg. Up to 1 metre, 15 kg	Upper and middle level of rivers and lakes.	5	Very possible	Skeletal parts
Erythrocultermongolicus (Basilewsky)	151-480 mm	Upper and middle level of sluggish water, e.g. river and lake.	4	Very possible	Skeletal parts
Xenocypris argentea Günther	300-500 g	In the middle and lower level of clean, slow-moving open water.	5	Possible	Skeletal parts
Plagiognathops microlepis (Bleeker)	No info	In the middle and lower level of slow-moving open water.	4 Fishing season is at early summer (spawning) and winter.	Possible	Skeletal parts
Acanthobrama simony Bleeker	103-183 mm	Lower and middle level of open water, e.g. rivers and lakes. Adaptive to various habitats.	4 Large number, quick reproduce rate. Important in the plain areas.	Very possible	Skeletal parts
Aristichthys nobilis (Richardson)	1 yrs: 500g, 2 yrs: 1,000g, 3 yrs: 1,500g, 4yrs: 2,000g. Up to 30kg.	Upper and middle level of water. Easy to capture.	4	Possible	Skeletal parts
Hypophthalmichthys molitrix (Cuvier et Valenciennes)	1 yrs: 500g, 2 yrs: 1,000g, 3 yrs: 1,500g, 4yrs: 2,000g.	Upper and middle level of large scaled water bodies.	4	Less possible	Skeletal parts
Cyprinus carpio Linnaeus	1 yrs: 500 – 1,000g, 2 yrs: 2,000g, 3 yrs: 2,500g, 4yrs: 3,000g, 5 yrs: 3,500 g.	Middle and lower level of water bodies. Highly adaptive.	5	Very possible	Skeletal parts

Carassius auratus (Linnaeus)	1 yrs: 100 – 150g, 2 yrs: 250 - 400g.	Lower level of water. Highly adaptive.	5	Very possible	Skeletal parts
Hemibarbus maculatus Bleeker	500g	Middle and lower level of large and slow-moving water bodies	4	Less possible	Skeletal parts
Gnatho pogon argentatus (Sauvage et Dabry)	91 - 122 mm	Middle and lower level of open and slow-moving water bodies	3 Small, but schooling.	Less possible	Non
Saurogobio dabryi Bleeker	138 – 173 mm	Middle and lower level of open and slow-moving water bodies	2 Small, but very common. Schooling fish.	Less possible	None
Misgurnus anguillicaudatus (Cantor)	95-159 mm	Inhabit shallow water and muddy area.	3 Small, but very common and easy to get.	Very possible	Skeletal parts
Silurus soldatovi meridionalis Chen	Up to 20 kg.	Deep and wide water bodies.	2 Few.	Less possible	Skeletal parts
Silurus asotus Linnaeus	1 yrs: 20 cm, 2 yrs: 40 cm. Up to 60 cm.	Adaptive to various water bodies.	5 Important freshwater fish.	Very possible	Skeletal parts
Pseudobagrus fulvidraco (richardson)	142 - 178 mm	Wide distribution; adaptive to various water bodies. Benthic.	3	Possible	Skeletal parts
Pseudobagrus eupogon Boulenger	148 - 250 mm	Benthic	2	Less possible	Skeletal parts
Pseudobagrus vachelli	Approx. 190 mm; can	Benthic fish. Inhabit	3	Less possible	Skeletal parts

(Richardson)	grow up to 0.5 kg.	sluggish water of rivers and lakes.			
Leiocassis longirostris Günther	Up to 1-2 kg.	Medium sized benthic fish inhabiting large and open water bodies i.e. downstream rivers.	3 Low yield.	Less possible	Skeletal parts
Leiocassis albomarginatus Rendhal	142-181 mm	Distributed in all streams and connected water bodies.	3 Small fish, but with wide distribution.	Not sure	Skeletal parts
Mugil cephalus Linnaeus	1 yrs: 200 mm. Up to 800 mm	Littoral fish inhabiting the upper and middle level. They are able to adapt freshwater, brackish water, and sea water. Migration.	5 Grow fast. Mugils are now cultivated.	Possible	Skeletal parts
Liza haematocheila (Temminck et Schlegel)	Normally 200-536mm; can grow up to 600mm, weighing 10kg.	Littoral fish which also adapts to brackish and freshwater.	5 Grow fast. Now cultivated.	Possible	Skeletal parts
Liza carinatus (Cuvier et Valenciennes)	Normally 200 mm.	Brackish water.	4	Possible	Skeletal parts
Monopterus albus (Zulow)	2yrs: 60-70 mm	Bethic and nocturnal fish. Carnivorous.	5 Widely adaptive and distributed.	Very possible	Skeletal parts
Lateolabrax japonicas (Cuvier et Valenciennes)	75-415mm; can grow up to 7.5-10kg	Carnivorous. Coastal area; fresh and brackish water. Spawning season is early spring.	5	Very possible	Skeletal parts

Siniperca chuatsi (Basilewsky)	2yrs: 250 mm	Open water with tranquil flow. Carnivorous.	4	Less possible.	Skeletal parts
Siniperca scherzeri Steindachner	135-312mm	Flowing water with gravel bed.	4 (at the Qiantang River region)	Less possible	Skeletal parts
Channa argus (Cantor)	225-403mm (collected samples)	Densely vegetated backwaters. Carnivorous.	4 Widely distributed	Very possible	Skeletal parts
Channa asiatic (Linnaeus)	145-240 mm	Similar to *C. argus*	1 Very few. They usually are tabooed in their distributional area.	No	None
Tephrinectes sinensis (Lacépède)	220 mm (captured specimen).	Benthic marine fish which can be found in the estuary area.	2 Few in the lower Yangtze region.	Less possible	Skeletal parts
Cynoglossus abbreviates (Gray)	182-303 mm (captured specimens)	Littoral fish which sometimes enters rivers to feed. The Yellow Sea and East Sea.	4 Fishing seasons include autumn/winter and early spring.	Possible	Skeletal parts
Fugu obscurus (Abe)	84-135 mm (captured specimens)	Littoral fish in shallow sea area of the Yellow Sea and East sea. Fugu can also be found in the Yangtze River, up to the middle Yangtze.	3 Fugu is favoured in the modern society, but might not be the same in the Neolithic due to its poisonous blood and viscera.	Less possible	Skeletal parts

6.1.3 Fish selection by fishing strategy

Chapter 3 has explained the selection of fishing tools and fishing methods for fish. Is the chosen fishing strategy one of the reasons that made snakeheads predominant? This section investigates whether there was a selection for fish, and on which criteria were these fish chosen over the others. There are two parts of analysis. First, the potencial targeted fish are listed, judging from their economic importance and the possibility to be preserved at site. The fish from Tianluoshan shall be included in this list. Second, does fishing strategy influence the selection of fish? The Tianluoshan people might not be capable of catching fish which requires advanced techniques such as deep-water fishing and long-distance sailing.

Table 6.1 lists 54 potential food fish in the lower Yangtze basin, featuring size, habitat, and economic significance. Whether a fish will present at Tianluoshan is estimated from its natural habitat. The economic significance of a fish is determined from its availability, size, growth rate, and taste, referencing Editorial Committee of Fauna of Zhejiang (1991) and Ni and Zhu (2005). Apart from large fish, small fish such as the Salangidae are commonly considered as a delicate cuisine due to their taste and amount. However, these fish are usually cooked and consumed entirely without leaving any skeletal remains. Plus, the bones are so small and fragile that they may not survive the digestive system. Therefore, if the Salangidae were consumed at Tianluoshan, it was basically impossible to be recovered. Apart from that, most fish in the list (42 species) more or less leave traces at site, most frequently skeletal parts, but sometimes only scute.

Table 6.1 indicates a selection of fish in two different levels. First, the fish found

at Tianluoshan are all included in this list, indicating the Tianluoshan people were aware of their value, and catch them on purpose. Second, fish with high value were selected from the rest by the Tianluoshan people. These fish have been used as important food fish for thousands of years, probably from the Neolithic Age until today, especially common carp, crucian carp, and catfish, which are evaluated as a high '5' in the column of 'economic significance'. The significance of some predatory fish such as snakehead and culter fish has been lowered as fish culture develops. They have been replaced by cultured fish such as black carp (*Mylopharyngodon piceus* (Richardson)), grass carp (*Ctenopharyngodon idellus* (Cuvier et Valencinnes)), silver carp (*Hypophthalmichthys molitrix* (Cuvier et Valenciennes)), and bighead carp (*Aristichthys nobilis* (Richardson)) (Table 6.1) because of productivity. The wild ancestors of these cultured fish, on the other hand, require different habitat environment from Tianluoshan (e.g. silver carp and bighead carp prefer large and open water bodies), or advanced fishing techniques to capture (e.g. black carp and grass carp are deep-water fish); therefore, they are less possible to present at Tianluoshan. There is a small group of unidentified fish (Table 5.1). Further analysis of these specimens may be able to find more food fish listed in Table 6.1.

Fishing is based on the knowledge of biological and behavioural characteristics of fish. Due to the diversity of fish habitats and behaviours, the fishing methods and fishing tools should vary accordingly. This section attempts to analyse how much the fishing methods may have played on the selection of fish species at Tianluoshan. The discussion starts from the biological and behavioural features of fish, and then leads to the fishing skills which need to be specially developed to catch certain species.

Subsequently, ethnographic examples which share commonalities with the Tianluoshan fish assemblages will be presented, to develop the suggestions.

Snakehead

The snakeheads from the Tianluoshan assemblage have been identified as the northern snakehead, the widest distributed snakehead in East Asia. Ichthyologic records indicate that it displays several distinctive behavioural features:

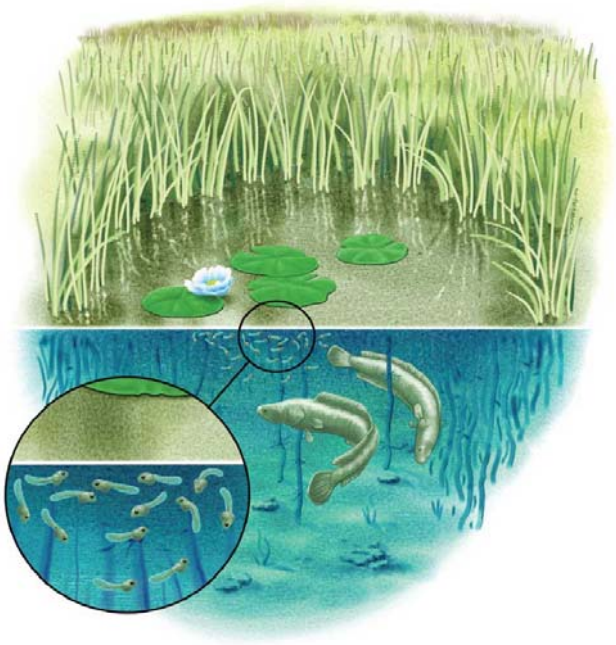


Figure 6.3 Illustration of snakehead adults guarding their larvae at the surface of their nest. Picture is adopted from the USGS website (fl.biology.usgs.gov).

1) Spawning and parenting. During spawning season, the parent snakeheads build nests in the shallow water by clearing a circular area in aquatic vegetation and creating a vertical column of water surrounded by plants. Sometime there are removed plants floating on the water surface above the nests. About 13,000 – 34,000 eggs are produced by a female northern snakehead during each spawning season. Eggs are buoyant due to a large oil droplet in the yolk mass. The parent snakeheads usually aggressively guard their nest for 3-4 weeks until the hatched larvae learn to

school and fend for themselves (Figure 6.3).

Fishermen are aware of this behaviour and use this knowledge to locate the nests and capture the snakeheads. The urge to protect their eggs and larvae causes the parenting snakeheads attack any presumed invaders. Villagers in the upper Yangtze River region (Sichuan Province) take advantage of this instinct to catch snakeheads during spawning seasons by deliberately irritating them with live bait such as frogs (Lan, 1958). The fishing tools are simple, usually scoop baskets or fishing hooks.

2) Migration and hibernation. Like other fish, snakeheads tend to move to a better environment before the arrival of cold or dry seasons. However, they can still survive even if they do not manage to escape. Snakeheads can bury them in mud, reducing metabolism as well as oxygen demand until the warm monsoon season comes.

In Southeast Asia, people dig ponds to attract snakeheads before their migration before dry season comes. These artificial refuges will soon become the graveyards of fish.

3) Sun-bathing. In summer and autumn, snakeheads like to float on the surface of water on sunny days, staying still for a long time if not disturbed. This is possibly because of the low oxygen level when the temperature is high. During the 'sun-bathing' time, snakeheads are exposed and fishermen can easily catch them by setting baits purposefully.

Common carp & crucian carp

Both common carp and crucian carp inhabit similar habitats and perform similar behaviours. The most important event for them is spawning, which usually occurs in

spring to early summer and varies depending on the climate and locations. The mature fish school in the shallow vegetated area during spawning season. Seasonal migration and spawning commonly happen to many fish species, making it a possible fishing season.

The interpretation indicates that both cyprinid and snakehead can be caught using different methods according to their different features, possibly at different times of year as well. The harvest of seasonal fishing of spawning fish tends to consist of mono-species fish, with similar body sizes. The fish remains from H1 (the fish bone pit) accord with the assumed seasonal fishing model. Size reconstruction suggests that the assemblage is mainly formed of crucian carp of similar body length, indicating a fishing event that specially focuses on crucian carp. On the contrary, the snakeheads perform a series of distinctive behaviours throughout the year, so that ethnographic evidence suggests they can be captured with several different methods as mentioned above. Different from the composition of H1, the deposits from the layers are dominated by snakeheads, which may imply a long term fishing economy which was developed based on the unique wetland environment around the settlement.

The reference case study: rice field fishing in Cambodia

When reviewing study cases from both archaeological and ethnographic records, I tried to find examples which meet two conditions to stimulate further discussion of the fishing strategies at Tianluoshan: 1) snakehead is included in the daily diet; or 2) the fish assemblage is dominated by snakehead or any other ichthyophagous fish. Unfortunately, there are very few eligible cases even in modern records, probably because snakehead is not a common commercial fish like carp. In much of the

literature, they are often treated as pests in fish farms due to their predatory behaviour towards other commercial fish (Courtenay and Williams, 2004).

The closest example is a modern case of rice field fishery in Cambodia. Rice fields are essentially artificial wetlands; hence they share similarities with natural wetlands, such as anoxic conditions, strong fluctuation of temperatures, etc. The fish inhabiting rice fields are basically the same as those species in wetlands, so that they can survive the harsh conditions. There are many advantages of keeping fish in paddy fields, since they remove the pests and weeds in the fields, fertilize the fields, reduce the use of pesticides and artificial fertilizers, and increase the harvest of the fields. As agriculture develops, people have gradually realized the benefits of the 'rice-fish eco-culture', and started to build up the rice field ecosystem intentionally, such as the rice-fish co-culture in Zhejiang Province, China (Xie et al., 2011). It should be noted that the fish from rice-fish eco-cultures can be both wild (e.g. Cambodia) and cultured (China).

In the case study of the rice field fishery in Cambodia, fish in rice fields can be classified into two types: white fishes, which are small herbivorous or planktivorous cyprinid species, and black fishes, which are mostly carnivorous, air breathers able to survive under low (or no) dissolved oxygen conditions (Gregory and Guttman, 1997). Snakehead is one of the representative species of the black fish.

Cambodian rice farmers employ different ingenious methods to catch rice field fish and other aquatic animals, including netting, hooking, trapping, harpooning, cutting by knife, throwing nets, and gaffing. Farming in Cambodia is highly depending on the season cycles; so are the fish behaviours. Therefore, the methods for fishing rice field fish vary due to the difference of targets and the change of seasons.

There are three seasons each year in Cambodia: the wet season, the cool season, and the dry season. During the wet season, which is generally from May to Mid-November, fish are caught as they come out of refuges or move between rice fields. Netting, trapping, and spearing are commonly used. Fish typically caught at this time of year include both white and black fish, such as danios, climbing perch, small catfish and snakeheads.

In cool seasons when the rice fields begin to dry, fish are caught during their migration trip from rice fields to deeper water areas. Trap ponds are dug in the rice fields and later drained manually to collect the fish by hand. The catch usually consists of medium-sized catfish, snakeheads, danios, spiny eels and anabantids, mainly black fish. Dry jump traps are also used to catch migrating fish, by blocking them with a bamboo screen. During this procedure, snakeheads are usually caught in the dry pit when they attempt to jump over or around the obstruction.

Farmers also dig deep trap ponds which are usually over three metres deep to trick the fish that they have reached a safe refuge where they can survive throughout the dry season. These fish are usually netted for household consumption in the following hot season when few rice field fish are available. The remaining fish can be caught by hand from mud when the ponds are finally pumped dry. This final catch usually consist only black fish, mainly snakehead and catfish with occasional anabantids and eels, because most white fish have been eaten by the predatory fish. At this time of year, fishing is very intense in all water bodies even the refuge area, usually by drying the water in shallow areas and netting in deeper water.

6.1.4 Discussion

Studies in rice field fishing in the Southeast Asia (Catling, 1992, Nesbitt, 1997,

Halwart and Gupta, 2004) show that carnivorous fish such as snakehead have taken a significant place in the fishing harvests due to their high adaptability of anaerobic water and their predation of the other herbivorous fish such as the cyprinids. Although exact proportions of each catch are not given in this case, the description indicates that the proportion of black fish increases from the wet season through the cool season until the hot season. Both black and white fish are caught during the wet season. The predominance of blackfish starts from the cool season. For the dry season fishing, data show that trap ponds catches are composed of only a few species, up to 90% are black fish, such as snakehead for 25-40% of the total catch weight, catfish for 35-40%, climbing perch for about 10-15%, and white fish (danios) only takes up 10-15%. The description of the fishing procedures and data analysis on the study case in Cambodia rice field fishing implies that the high percentage of black fish during fishing is due to their high adaptability of anaerobic water and their predator position in the ecosystem.

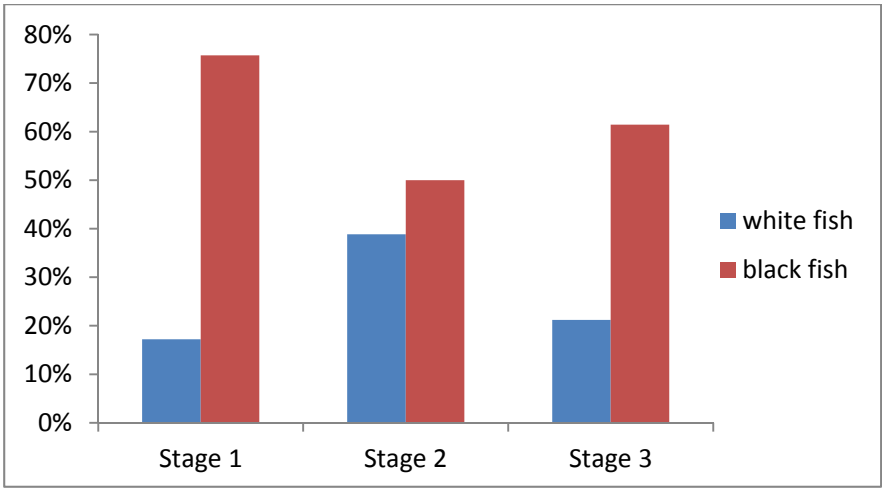


Figure 6.4 The relative importance of black fish vs. white fish at Tianluoshan.

This study provides reference data for the discussion of the Tianluoshan fish assemblage. Classifying wetland fish species at Tianluoshan blackfish and whitefish,

blackfish includes snakehead and catfish, and whitefish includes common carp and crucian carp. As Japanese sea bass is estuary fish and culter fish is river fish, they are not included in this discussion. In Stage 1, blackfish make up the very high proportion of 75%; they then drop back to about 50% in Stage 2, and increased again in Stage 3. For white fish, there is a significant increase of white fish in Stage 2, but they drops back to about 20% in Stage 3.

For the case study in Cambodian rice field fishing, the variation of black and white fish proportion is caused by different fishing strategies between seasons. However different, the change at Tianluoshan may have been caused by more complicated factors, such as taphonomic issues, environmental issues, and fishing strategy issues. Here I would like to address one hypothesis which may have led to this situation.

As stated before, blackfish especially snakeheads, have an extremely wide adaptability, that they are more adaptive to shallow water habitat which is more anoxic. Generally, the blackfish and whitefish at Tianluoshan respectively represent the shallow water and deep water fishing. Therefore, from Tianluoshan Stage 1 to Stage 3, the exploitation of the wetlands has experienced a process from shallow water (margin wetland) to deeper water (central wetland) and back to shallow water (margin wetland). It indicates that the exploitation of food resources was first happening in the areas closest to the settlement, i.e. the margins of the wetlands, and then went further to deeper areas, and again back to the nearer areas. The relations between fishing strategies and the foraging of aquatic plants shall be discussed in Chapter 8.

From the similarities between Tianluoshan wetland fishing and the rice field

fishing in Cambodia, we may presume that similar or at least methodologically related fishing techniques were applied at middle-Neolithic Tianluoshan, so that the catches consisted of a great harvest of blackfish especially snakeheads. We may not know what exactly the fishing methods were, but the underlying spirit and rationale might have been the same.

6.2 Investigating the fishing strategies at Tianluoshan: ethnographic and archaeological analysis

Fishing hooks, harpoons and net sinkers are the most commonly excavated tools at fishing sites. However, as described in Chapter 3, most fishing tools will not be preserved at archaeological sites as they are made from organic materials such as fibre nets and wooden traps. On the other hand, we would not expect any fishing tools when fish were caught with bare hands, which was quite common according to modern and ethnographic records.

This section aims at investigating the fishing methods at Tianluoshan through archaeological materials, fish remains, and comparison with ethnographic records. As there is rarely direct archaeological evidence for fishing strategies, the main idea of this deduction is to narrow down the range of possible fishing methods by various factors. First, the fish catching methods shall be narrowed down by considering the environment, i.e. wetlands in the case study of Tianluoshan. Subsequently, these selected methods will be examined with consideration of information from the ethnographic records, which will provide insights into the practdicalities of fishing. Third, the fish remains data itself will be used. Finally, the reported artefacts from Tianluoshan as well as the Hemudu site will be reconsidered to find out if there are

any possible fishing gear.

6.2.1 Wetland fishing methods: an overview

There are many restrictions in fishing in wetlands, due to the specialized environmental settings and ecosystem. In deep and vast water bodies, netting and hooking can be the most applicable methods; but in shallow water bodies like wetlands, some methods may not be suitable, such as netting and sometimes hooking. The low water level makes it difficult to throw or set nets; furthermore, the wetland plants are obstacles for both netting and hooking. However, ethnographic evidence show that some fishing equipment is especially applicable for wetland fishing, such as scoop baskets, traps and a variety of “falling gear”, which are nets or pots particularly designed to clamp down on top of the fish and close in on them (von Brandt, 2005).

The first and simplest method for catching fish is gathering by hand. Gathering fish by hand can be found in all shallow water areas, such as sea coasts, floodplains, and wetlands. Although in wet land, most fish are too quick and sensitive to catch by hand. So the harvest from hand gathering mainly include slow moving fish, crayfish, shellfish, fish roe, etc.

A scoop basket is an old fishing gear made of plant materials, such as wood and bamboo splinters, shaped as shallow plaited or woven plates (Figure 6.5). In the ethnographic fishing example from the Upper Yangtze River mentioned above (Lan, 1958), scoop baskets are frequently used when catching snakeheads, no matter whether in spawning season, post-hibernation or during “sun-bathing”.

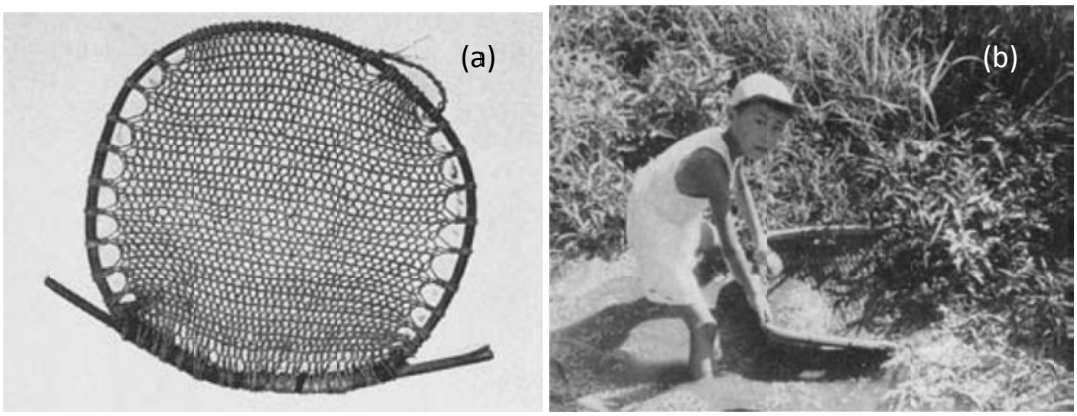


Figure 6.5 Scooping fishing tools by ethnographic evidence: (a) flat scoop net from Geelvink bay, New Guinea; (b) winnowing basket used as scooping basket in Japan, indicating that a tool can be multifunctional. Pictures are cited from Gabriel et al (2005, P351-353).

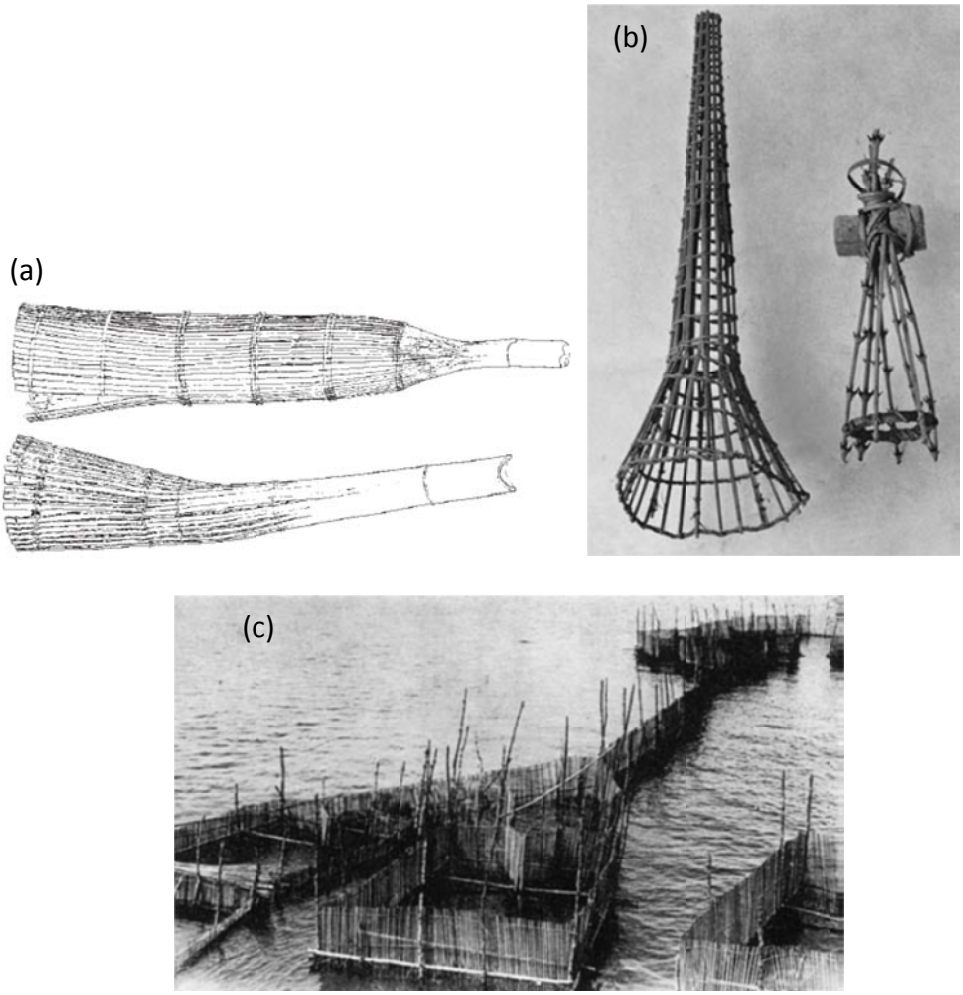


Figure 6.6 Examples of trapping vessels and trapping barriers. (a) Tubular traps made of split bamboo, without funnels, used in parts of India; (b) thorn-lined traps of Oceania; (c) fences arranged as traps off the Ivory Coast (Photographed by Steinberg, 1965). (von Brandt, 2005)

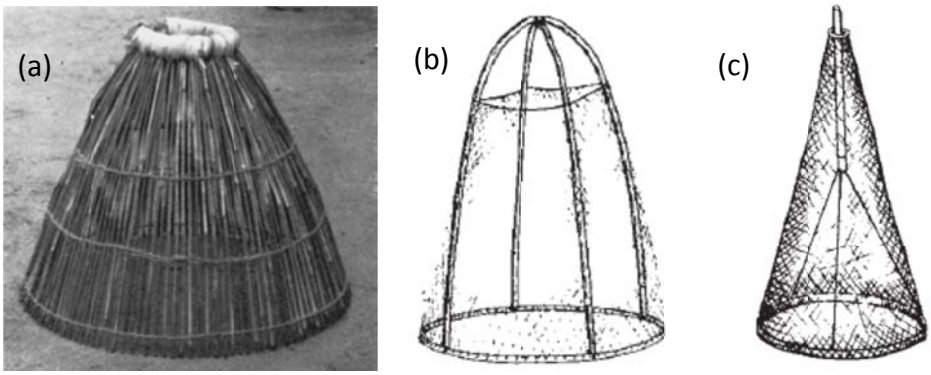


Figure 6.7 Cover pot, lantern net and cover net: (a) cover pots used in Kerala, southern India; (b) lantern net in southern Germany; (c) Hungarian cover pot. (von Brandt, 2005)

Fishing traps are usually set in flowing water bodies such as rivers and streams where fish are meant to pass. There are two general types of traps: trapping barriers and trapping vessels (Figure 6.6). Trapping barriers are used to create a passage with fences, to lead fish into a container, thus the fish can be caught by draining the water or collecting with other tools (von Brandt, 2005). They are also built in the tidal and flooding areas to stop fish from retreating back to rivers or the ocean. Migrating fish can be efficiently captured using trapping weirs. The principle of using trapping vessels is to attract fish into them, while making it impossible for them to get out, by narrowing the other end or setting backward spikes to make fish unable to turn around and therefore they get stuck in the traps. In still water bodies like wetlands, bait may be required for luring fish.

'Falling gear', as described above, are a variety of tools which are clapped down on the fish or other animals to be caught, which are then taken through the opening above (Figure 6.7). This method is primarily used for capturing individual fish and those that have dug themselves into the mud. It will only be successful in turbid, especially muddy, water where many plants grow, so that the prey will not easily escape. The common falling gears include cover pots/nets, lantern nets, and cast

nets. These gears are made of different materials, including wood, split bamboo and netting, and are of varied size, from 15 cm to a few metres in diameter. Fishing with falling gear depends on the depth of water, since cover pots/nets and lantern nets can only be used in knee-deep water, while cast nets are suitable for deeper water. When taking the prey out of the falling gear, tools like scoop baskets may be required, in order to avoid biting or stinging from the fish (von Brandt, 2005).

The environmental limitations of wetlands have eliminated many common fishing methods, and narrowed the possible choices to a few methods. Nevertheless, these wetland fishing gear share a common feature: they will rarely leave archaeological evidence, even in a waterlogged environment like Tianluoshan. This characteristic makes it difficult to investigate the fishing techniques and skills during the Hemudu Period from direct archaeological evidence.

6.2.2 Modern ethnographic examples: Rice field fishery

The modern rice field fishing is chosen for study for three reasons. First of all, rice field has similar environmental settings to natural wetlands. Rice field is defined as 'a successor of shallow marshes or a lowland area which can be supplied with adequate water' (Fernando, 1993, Ali, 1998), characterized by shallow water and fluctuations in water temperature, acidity and dissolved oxygen (Halwart and Gupta, 2004). Essentially, rice fields can be seen as artificial wetlands or specialized wetlands. Secondly, primitive paddy fields have been found at Tianluoshan (Fuller et al., 2011, Zhang et al., 2010, Zheng et al., 2011), so it can be seen as a transitional form between natural wetlands and modern rice fields. Therefore, studying modern fishery in rice fields can also help to interpret the fishing economy at Tianluoshan.

Finally, rice field fishing is still frequently practiced in modern society, which provides abundant comparison samples for this study.

Generally speaking, fish and other animals in the rice fields are mainly affected by five factors: water level, water temperature, dissolved oxygen, acidity and unionized ammonia (Halwart and Gupta, 2004). But unlike wetlands, where oxygen levels are vital for fish, shallow water is probably the most significant and crucial factor in the rice field ecosystem, especially for fish. It is not only for the reason that it restrains the existence of living organisms in the environment, but also because water levels influence other environmental factors as well such as water temperature. The water depth in rice fields is usually about 2.5 cm and 15.0 cm (Halwart and Gupta, 2004), and can be as deep as 30 cm (Fernando, 1993), making it unsuitable for organisms requiring deeper water. It is obvious that the shallow water restrains the existence of fish, including their species, population, and size composition. The deeper the water is, the more chance for fish to survive.

In addition, shallow water is easily affected by a change of weather conditions, such as solar radiation, wind velocity, air temperature and rainfall (van der Valk, 2006). The low heat capacity and the greenhouse function of flooded rice fields make the temperature of water even higher than soil. Usually the water and soil temperature in a rice field is higher than the air temperature (Halwart and Gupta, 2004). Besides, the water temperature in rice fields varies much between the day and night, making it more difficult for fish and other animals to adapt. As the environmental conditions are intensified, only a few fish can tolerate the adverse environment of rice fields, including the air-breathing fish, as well as common carp and crucian carp.

Rice field fishery is common in Southeast Asia. As introduced in the previous section, several different fishing tools and fishing methods are applied during routine fishing, including netting, spearing, hooking, harpooning, gaffing etc. Apart from that, catching fish with bare hands is also frequent in rice fields, where the shallow water makes it feasible. This gathering by hand is even easier after seasonal draining the water in rice fields. In south China, hand gathering is still quite common for catching carp in the paddy fields.

From the similarities between Tianluoshan wetland fishing and the rice field fishing in Cambodia, we may presume that similar or at least methodologically related fishing techniques were applied at the mid-Neolithic Tianluoshan, so that the catches consisted of a great harvest of blackfish, especially snakeheads. We may not know what exactly the fishing methods were, the idea is worth considering further.

6.2.3 Archaeological evidence for fishing in the Hemudu Period

Due to the limitation of archaeological material, I have reviewed the relevant artifacts from both Tianluoshan and Hemudu. Currently from Tianluoshan, no fishing tools like harpoons or net sinkers have been reported (Sun, 2011). At the site of Hemudu, although there were huge amount of fish remains uncovered, direct evidence of the fishing gear is also very rare.

Only a few fishing tools have been uncovered from the site of Hemudu: two stone net sinkers and two harpoons made of bone (Figure 6.8) (Zhejiang Province Institute of Archaeology and Cultural Heritage, 2003), and the number of fishing tools is very few considering the enormous amount of fish remains, indicating that the fishing gear must have been far more abundant than those that have been

preserved.

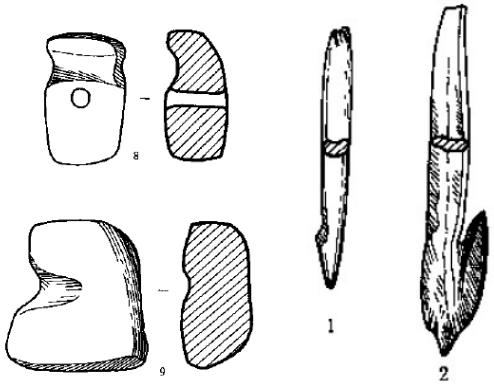


Figure 6.8 The excavated fishing tools from Hemudu, net sinkers (left) and harpoons (right) (Zhejiang Provincial Institute of Cultural Relics and Archaeology, 2003).

There could be two explanations for this scarcity of fishing tools: on one hand, most of the fishing gear was made of organic substance such as wood, bamboo, rope, etc., which could be hardly preserved; on the other hand, people might use nonconventional fishing gears which had not been correctly identified by archaeologists. For example, as indicated in Figure 6.5 (b), tools can be multifunctional, such as a winnowing basket could possibly be used as a scoop basket.

Apart from the tools in Figure 6.8, there are a lot of potential fishing gear and tools. Considering the basic principles of fishing and hunting, there is no clear boundary between fishing tools and hunting tools. Even today the tools are not exactly separated. For example, nets can be used for catching fish, birds, and mammals. Another example is projectile tools, which are frequently used in hunting and fishing, especially for fishing in shallow water bodies. Lawrence (1969) has summarized the descriptions of Aboriginal river fishing methods from the journals of the explorers and first European settlers in Australia. A wide variety of spears, nets, and traps was used instead of hooks and lines. Spears were preferred to fish in

swamps and lagoons, as well as in rivers when the water level was low and the fish were concentrated in pools.

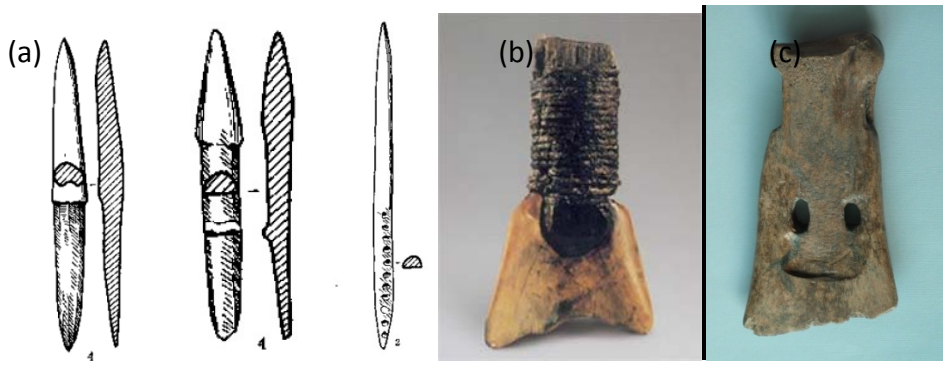


Figure 6.9 Other possible fishing gear: (a) projectile points from Hemudu; (b) bone spade (or Si) from Hemudu; (Zhejiang Province Institute of Archaeology and Cultural Heritage, 2003) (c) bone spade from Tianluoshan.

Beyond all questions, a great number of projectile tools have been found at both Hemudu and Tianluoshan (Figure 6.9 a). They can be morphologically identified as spear heads and arrow heads.

The ethnographic sample in Southeast Asia suggests that trap ponds are frequently used and the catches through this method mostly consist of blackfish, which is similar to the fish composition at Tianluoshan. However, it is very rare to find direct archaeological evidence to support this fishing method. Under this circumstance, surely digging tools are required. A distinctive bone spade has been excavated at Tianluoshan and Hemudu, also known as '耜 Si'. Bone spades are usually made from scapulae of large artiodactyls such as water buffalo and sambar. Pelves of these animals are also occasionally used. The scapula or pelvis is pierced, trimmed and attached to a wooden handle (Figure 6.9 b). Examples have only been found at the sites of Hemudu Period, and are considered as rice field farming tools and digging tools (Zhejiang Province Institute of Archaeology and Cultural Heritage and Zhejiang Provincial Museum, 1978, Zhejiang Provincial Institute of Cultural Relics

and Archaeology, 2003, Sun, 2011). As described before, many tools can be multifunctional, and a bone spade is possibly another example.

6.2.4 What do fish remains imply for the fishing methods?

Chapter 3 has summarized the selection of fish body size by several common fishing methods, such as hand gathering, poisoning, spearing, netting, trapping, etc. Some fishing methods tend to catch fish regardless of their size, while the others are quite selective due to factors such as net eyes. Even for the selective fishing methods, the selected size range varies. In this section, the range of fishing methods can be narrowed down I will try to rule out the less possible fishing methods by analysing the reconstructed body length of fish from Tianluoshan.

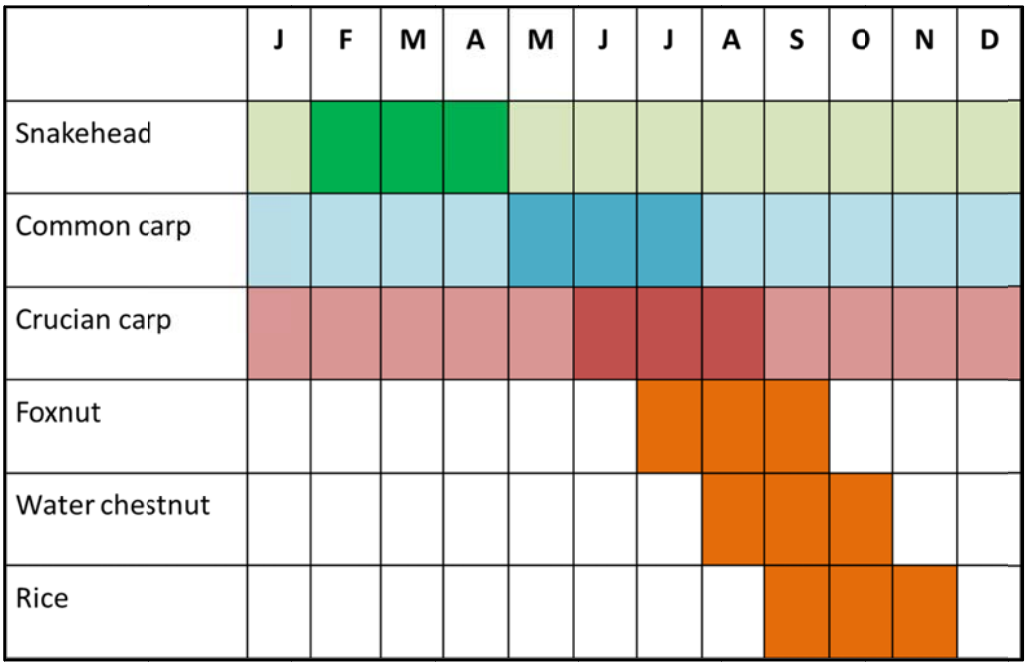
The body lengths of the predominant fish have been reconstructed in Chapter 5. The distrubution curves are respectively shown in Figure 5.8, Figure 5.10 and Figure 5.13. The graphs show a distinctive selection of fish by body size. Yet, it is quite difficult to decide the exact fishing methods merely from fish size reconstruction. On account of the previous analysis, the wetland fishing techniques, including trapping, fishing by scoop basket and falling gear, could have been practiced at Tianluoshan.

Interestingly, although the sizes of the three predominant fish vary greatly from each other, the size reconstruction indicates that the selection by size is quite similar, concentrating on the individuals between 140 mm and approximately 450 mm. Hence, for crucian carp which is much smaller than the other two species, the size of fish selected tends to be 140 mm and above. This result indicates that fish selection could possibly be caused by fishing methods. It also infers that those three species were possibly captured using the same fishing methods, rather than being targeted

by individual species.

In brief, fishing for subsistence is a complicated practice and many different fishing methods have been applied at any site, including Tianluoshan. The analysis of fish size, however, can be used to support a proposal for the fishing strategy at Tianluoshan. It suggests that methods selective by fish size were commonly employed; considering the environmental context, methods could have included trapping, casting and scooping.

Table 6.2 Seasonality of fishing at Tianluoshan, comparing with fruiting period of selected aqua plant taxa based on *Flora of China* and *Flora Hubeiensis* (Fuller et al., 2011).



6.3 Scheduling the exploitation of aquatic resources

The fishing seasons at Tianluoshan have been analysed in Chapter 5, showing that fishing was practiced throughout the year, but it was more intense in certain months. This conclusion is based on the study of snakehead remains. Meanwhile, the fishing seasons of cyprinids have been investigated previously by Nakajima and

colleagues, suggesting that they were captured mostly during spring to early summer (Nakajima et al., 2010a, Nakajima et al., 2011).

It appears that the fishing schedule is arranged targeting different fish species. The catches of snakeheads and cyprinids are clearly practiced at different times of year. It also explains the composition of the fish assemblage in H1: it represents a catch targeting crucian carp in early summer; hence there are few snakeheads and other fish. On the other hand, the seasonality timetable indicates that fishing techniques targeting specific fish at different times of the year might be preferred at Tianluoshan.

Table 6.2 shows the exploitation of other resources beyond fish. The schedule of exploiting the common aquatic resources indicates that the wetlands were constantly used for subsistence. As the harvest of aquatic plants is highly restricted by seasonality, fish may well have been the routinely procured resource for consumption. In the following chapters, the seasonality of exploiting terrestrial resources shall be added to the scheduling table.

6.4 Discussion and conclusion

Previous research shows that Tianluoshan was located beside a large area of wetland, which provides great abundant of aqua resources for subsistence, such as water chestnuts (*Trapa natans*), foxnuts (*Euryale ferox*), water buffalo, and the cyprinids (Fuller et al., 2011, Kanehara and Zheng, 2011, Zheng et al., 2011, Nakajima et al., 2011).

Tianluoshan presents contrasting evidence about fishing in subsistence: an extremely rich assemblage of fish remains, but without any fishing tools. In order to

answer the questions raised at the beginning of this chapter, the discussion is built up in a deductive order, starting from investigating the internal factors of the elements which are related to the fishing subsistence, such as the environment, fish species, the general fishing methods, etc. The discussion on the natural factors provides the theoretical possibilities, and the ethnographic examples are the applicable practices of the theories. The consideration of ethnographic cases emphasizes the similarities of some to Tianluoshan. This is why the examples of modern rice field fishing are chosen as reference cases.

Due to the lack of archaeological materials, the question for fishing methods should be considered through a different way, by gradually narrowing down the general fish catching methods to a specific site like Tianluoshan. On the other hand, I also attempt to discuss the fishing methods through the analysis of fish remains. Through quantitative analysis, the body length reconstruction in Chapter 5 has inferred that fish methods with selectivity by size were employed at Tianluoshan.

Subsequently, by identifying the capture season of each individual, the fishing seasons at Tianluoshan is revealed. It appears that fishing was practiced throughout the year, but intensified in certain months. For snakeheads, the intensified fishing mostly occurred in spring; but as time goes by, the fishing season extended. The concentrated fishing seasons for the cyprinids occurred slightly later, normally from late spring to summer. By integrating with the seasonality of aquatic plants, the exploitation of the aqua resources is regularly organized at different seasons of the year.

6.4.1 Fishing subsistence at Tianluoshan

The presence of substantial quantities of fish remains confirms that fishing was an important component in the subsistence economy at Tianluoshan. The analysis indicates snakehead, crucian carp, and common carp can be regarded as co-staples. The limited range of fish species suggests that the inhabitants of Tianluoshan were specialized fishers rather than broad-spectrum foragers. The presence of wetland, riverine, estuarine, and marine fish indicates varied environment for fish exploitation; however, detailed analysis of the three predominant fish suggests that fishing mostly occurred in a rather concentrated area, i.e. the wetlands.

Integrated with the archaeobotanical results, the importance of wetlands in the Tianluoshan subsistence is highlighted. Archaeobotanical research indicates that aquatic plants from the wetlands, including wild water chestnuts, foxnuts, and cultivated rice, were the major plant food resources at Tianluoshan throughout the Hemudu period. In addition, although not included in this thesis, a large number of soft-shelled tortoise and waterfowl which inhabit the wetland has been uncovered from Tianluoshan. These findings indicate wetland might be the core region for subsistence at Tianluoshan. The importance of wetland shall be further discussed in Chapter 8 by comparing various environmental types around Tianluoshan.

According to the analysis in this chapter, the fluctuating ratios of blackfish and whitefish possibly indicates exploitation of different areas of wetlands, thus reflects the change of resource exploitation strategies during the site occupation. The second shift shown in Figure 6.4 can be seen as the indication to the transition from foraging to agriculture. Archaeobotanical research of Tianluoshan has shown that rice cultivation was in the incipient phase during the Hemudu period, and rice gradually

took the place of the wild resources such as acorns (Fuller et al., 2009, 2011). Rice growing fields have been discovered beside the Tianluoshan village (Zheng et al., 2009), but in the incipient phase, it might be formed by simply modifying the margin of the wetlands to make them suitable for planting rice (Fuller et al., 2011). There might not be obvious boundaries between the incipient rice fields and the wetlands, so that the primitive rice field was still part of the habitat for wetland fish. Therefore, the development of rice cultivation turned the margin wetlands more important area for routine subsistence, where both farming and fishing can be practiced. On the other hand, the existence of fish in incipient rice fields also greatly benefit rice production, by clearing out weeds and pests, releasing the fixed minerals in soil (e.g. phosphorus), etc. The fish-rice ecosystem might have been encouraged along with the development of rice cultivation. This assumption requires examination with more materials in the future.

6.4.2 Contribution to research method

Overall, the retrieval of fish remains at Tianluoshan has been a breakthrough in Chinese archaeology. Prior to this, archaeologists did not, and could not know how important a role fishing played in the subsistence economy. However inevitably, the retrieval strategy has brought many problematic issues which have made the research complicated. The fish remains are sieved, collected and primarily sorted without the guidance from zooarchaeologists, so that additional sieving samples are taken, and many calculations are undertaken during quantitative analysis to minimize the biases that have created by various retrieval methods and decisions.

Similar to the identification of any other animals, it is difficult to identify every

fish bone to species, especially when the assemblage is mainly composed of vertebrae. However, the study of fish size and seasonality has raised the bar for the accuracy of identification to a much higher level: the skeletal elements required for both types of study must be retrieved and identified to species, with the help of reference materials.

Fortunately, the fish assemblage at Tianluoshan consists of common fish species which are still consumed in the lower Yangtze River region. Snakehead can be simply identified to species from the basioccipital, the most frequently studied skeletal part in this project, as there are only five species in the genus *Channa*, and most of them do not inhabit this area.

This study also reveals the importance of reference specimens, for identification, body length reconstruction, and seasonality estimation; the required sample size required increases greatly from the first to the last subject. On the seasonality reconstruction through otoliths analysis at Raversijde, Belgium, 4595 modern plaice otoliths and 1297 haddock otoliths were collected and studied (van Neer et al., 2004). The samples were collected in different months of the year, and more than 100 specimens are collected in each month, to guarantee large samples and therefore accuracy. However, those numbers are far more than this project was capable of. Although I have worked hard to collect reference specimens, there may still be inevitably some error caused by the deficiency of reference samples.

Two methods for seasonality estimation were applied in this study: estimation by body length for the cyprinids, and the seasonality of snakeheads was determined from growth rings. Both analysis procedures and results indicate that estimating by growth rings is a better method for approaching seasonality of fish, although it

ideally requires large numbers of reference samples, and accuracy of results can be affected by small samples.

Chapter 7 Range and relative importance of mammalian taxa

Apart from the fish remains, the mammalian assemblage is another major component of the Tianluoshan faunal remains. Although its NISP is smaller, the volume and weight of preserved mammalian remains are much more than fish remains.

This chapter presents the original data of mammalian remains from Tianluoshan, and discusses the subsistence economy from the analysis. In order to interpret the subsistence economy, three questions are addressed. The first question is also a heated topic in Chinese archaeology: are the pigs from Hemudu Period domesticated? The pig remains are analysed from the aspects of morphometric statistics, cull patterns, and proportional analysis. A comparison with the pig remains from other archaeological sites in the study area will help to solve this question. Second, what are the hunting strategies for deer? I attempt to answer this question by analyzing the remains of two predominant deer species at Tianluoshan, sika deer and muntjac. They are different in size and habitat, and it may help to detect if the strategies target specific species. Third, what was the subsistence economy of the Hemudu Culture? The analysis will be integrated in order to reach a final conclusion.

7.1 Range and relative importance of taxa

A total number of 20,185 bones and fragments from the first four seasons of excavation are included in this study. More specimens have been retrieved in the later seasons due to the introduction of sieving. 6,378 specimens can be identified to

species, which is nearly a third of the total number.

The remains are generally preserved in good condition. The remains from lower layers are barely weathered, possibly because they became waterlogged soon after discard. Specimens from the upper layers (layer 3 and 4) are slightly weathered, due to the rise and fall of water levels during deposition. Gnawing marks by carnivores can be observed on a few cancellous ends of long bones. Gnawing marks by rodents can be observed occasionally; but given that some of them are caused after excavation and cannot be told apart, these marks are not considered in this study.

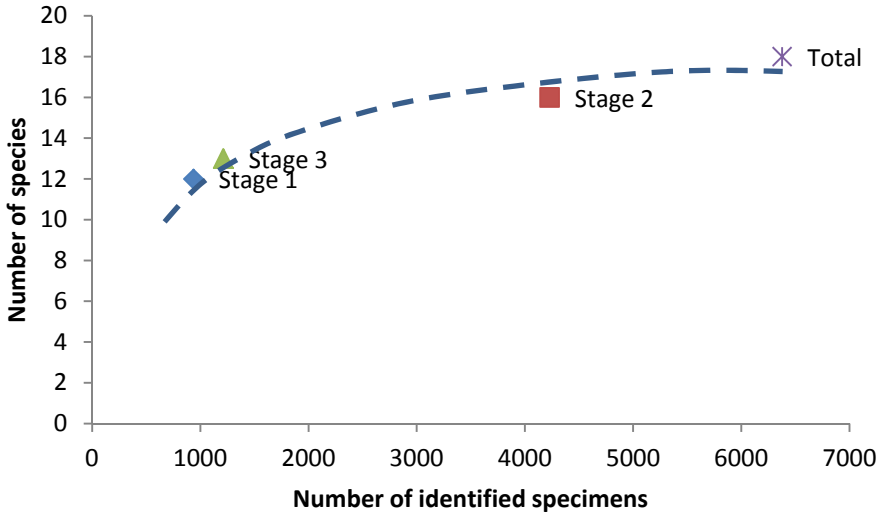


Figure 7.1 The change of sample size (NISP) and species richness (number of species) at Tianluoshan. The relationship between two factors is demonstrated by the regression curve. The formula for this particular curve is: y=2.9204ln(x)-7.9224; R^2=0.984.

The statistical analysis is processed by stage, and the sample sizes differ between three samples. Stage 1 has the smallest sample size, as most parts of the strata are kept unexcavated at present; the major part of the excavation area is currently halted at the bottom of layer 6 for the conservation of the wood constructions. Stage 2 has the largest sample size, and the specimens from those strata are preserved in good condition. The sample size of Stage 3 is also small, probably due to the retrieval

method of hand-picking. Apparently these specimens were collected not long after the excavation started, before sieving was employed.

Table 7.1 The NISP and proportions of taxa.

Taxon	Stage 1		Stage 2		Stage 3	
	NISP	%	NISP	%	NISP	%
Elephant (*Elephas maximus*)	0	0.0	0	0.0	1	0.1
Water buffalo (*Bubalus Mephistopheles)*	64	6.9	214	5.1	31	2.6
Sambar *(Cervus unicolor)*	120	12.8	444	10.5	58	4.8
Père David's deer (*Elaphurus davidianus)*	5	0.5	10	0.2	0	0.0
Sika deer (*Cervus Nippon*)	341	36.7	1618	38.3	527	43.4
Water deer (*Hydropotes inermis)*	0	0.0	5	0.1	1	0.1
Muntjac (*Muntiacus reevesi)*	164	17.7	787	18.6	165	13.6
Cervidae	78	8.4	403	9.5	223	18.4
Pig (*Sus* sp.)	114	11.6	443	10.5	156	12.9
Macaque (*Macaca mulatta)*	18	1.9	57	1.3	9	0.7
Black bear (*Selenarctos thibetanus)*	1	0.1	0	0.0	0	0.0
Dog (*Canis familiaris)*	1	0.1	6	0.1	2	0.2
Raccoon dog (*Nyctereutes procyonoides)*	4	0.4	3	0.1	2	0.2
Badger (*Meles meles)*	7	0.8	17	0.4	4	0.3
Otter (*Lutra lutra)*	0	0.0	5	0.1	2	0.2
Marten (*Martes fiavigula)*	0	0.0	9	0.2	0	0.0
Civet (*Paguma larvata)*	0	0.0	2	<0.1	0	0.0
Cat (*Felis* sp.)	5	0.5	3	0.1	3	0.2
Carnivores	15	1.6	201	4.8	29	2.4
Porcupine (*Hystrix hodgsoni)*	0	0.0	1	<0.1	0	0.0
Subtotal	937		4228		1213	
Unidentifiable (fragments)	518		4356		2475	
Total	1446		8584		3688	

A total of 18 species have been identified from the entire Tianluoshan mammalian assemblage, but the number of each stage is different due to sample size. Figure 7.1 shows that the number of species and NISP are positively related: the

number of species increases at a decreasing rate as the sample size grows. The linear regression can be expressed by an equation, and the strength of the relationship is demonstrated by the variance (R^2).

The NISP and relative abundance of identified taxa are presented in Table 7.1. It reveals that the mammalian assemblage from Tianluoshan consist of prey animals, indicating a subsistence setting. The compositional species represents a diverse spectrum, ranging from common ungulates to primates. Considering both natural and human factors, all animals can be generally classified into three groups: wild animals, domesticated animal, and extinct animals.

Most animals in the Tianluoshan assemblage are wild, including all the cervids, most carnivores, and monkeys. Proportionally, they also take the major part of the Tianluoshan assemblage, indicating a very important part played by hunting in the subsistence economy. Accordingly, the environment surrounding Tianluoshan is the main resource for animal food. The exploitation to the natural environment shall be discussed in the next Chapter.

Dog is the only assured domestic animal at Tianluoshan. Water buffalo (Bubalus Mephistopheles) was first considered as domesticated, but was excluded recently based on biomolecular data. Previous research tends to believe that pigs had been well domesticated by the Late Neolithic period (Yuan and Flad, 2002, Yuan and Yang, 2004, Luo, 2007). However, Table 7.1 shows that the pig NISP stays at a rather low percentage (approx. 10-13%) throughout three stages at Tianluoshan. This proportion is too low for a 'well-domesticated' species which is fed as meat resource, especially when compared to the wild prey percentage. Therefore, this thesis re-evaluates the domestication process of pig in the Hemudu Culture from four aspects,

and will be presented in Section 7.5.2.

The faunal assemblage also contains two extinct species, the giant-antler muntjac (*Muntiacus gigas* sp.) and Mephistopheles water buffalo (*B. Mephistopheles*). The giant-antler muntjac was named after the robust antlers (Figure 7.2 - b) found at Hemudu which were distinctive from any other muntjacs alive (Natural History Section, 1978), but recorded speciemens are few, only at a few sites in the middle Yangtze River region (Wu and Zhou, 2005). A similar species, the giant muntjac (*Megamuntiacus vuquangensis*) was discovered in Laos in 1994 (Evans, 1995, Schaller and Vrba, 1996, Timmins et al., 1998). It bears a pair of large antlers similar to the Holocene giant-antler muntjac (Figure 7.2). A few giant-antler muntjac specimens from Tianluoshan and Hemudu have been taken for DNA testing in order to find out whether there is genetic connection between the modern tropical species and the extinct species.

Archaeological evidence indicates that the Mephistopheles water buffalo was a widely distributed species during the Neolithic and Bronze Age in China. It was considered to be the earliest domesticated water buffalo in East Asia, as well as the ancestor of modern domesticated water buffalos, until recent DNA research revealed it was an extinct wild species with no direct connection to the modern domesticated water buffalos in China (Yang et al., 2008). Apart from these extinct species, there are animals which disappeared from the Yangtze River region long ago, including the Asian elephant (*Elephas maximus*) and sambar (*Cervus unicolor*). The elephant remains only include a few pieces of worked teeth and remnants, so it is unsure where these materials originate. However, elephant skeletal parts have been found at several Neolithic locations in the Yangtze River region and even north areas, such

as Hemudu, Luojiajiao, and Dawenkou, indicating that elephant might have inhabited a broad area of East Asia thousands of years ago. There are more animals belonging to this category, such as *Phinoceros sondaicus*, *Didermocerus sumatrensis*, and *Macaca arctoides* from the site of Hemudu.

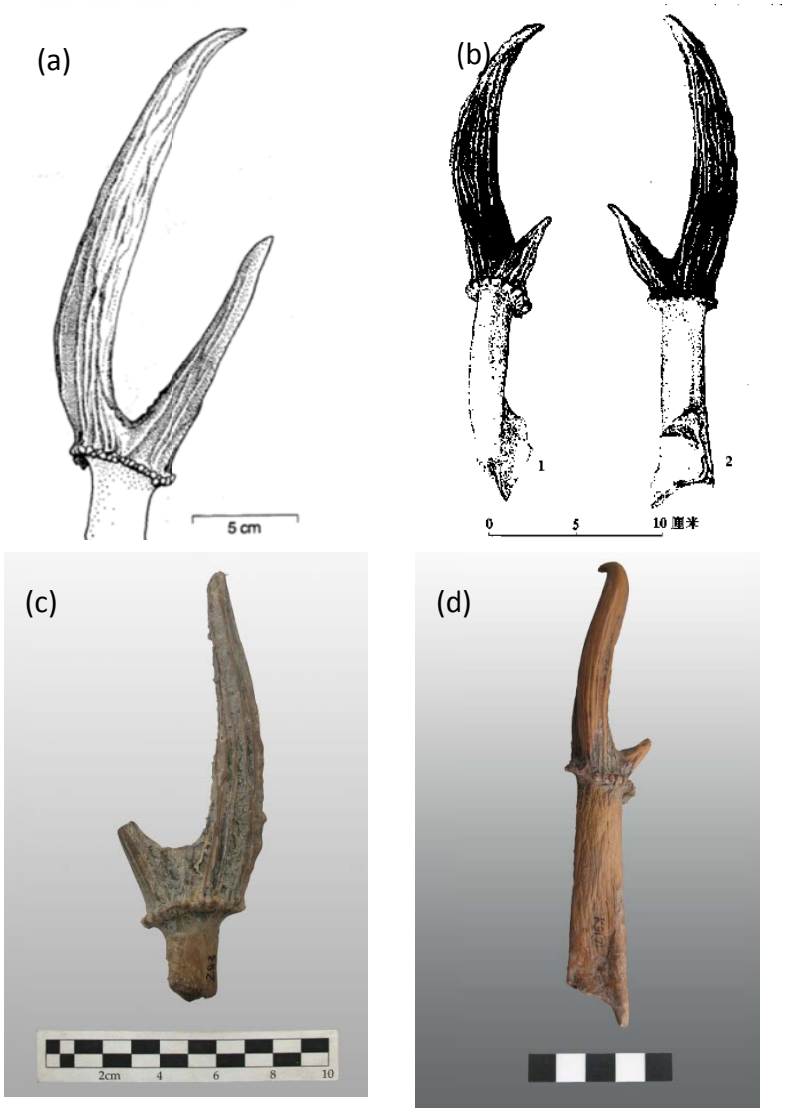


Figure 7.2 The antlers of muntjacs: (a) giant muntjac (*Megamuntiacus vuquangensis*) in Laos (Schaller and Vrba, 1996, Figure 4); (b) giant-antler muntjac (*Muntiacus gigas* sp.) from Hemudu (Zhejiang Provincial Institute of Cultural Relics and Archaeology, 2003, Figure 98); (c) giant-antler muntjac from Tianluoshan; (d) muntjac from Tianluoshan.

Overall, Table 7.1 reveals two significant characteristics of the Tianluoshan faunal assemblage: diversity but high selectivity. This assemblage shows a broad spectrum

in species, ranging from large ungulates inhabiting wetlands to small arboreal mammals; they also represent varied habitats. Meanwhile, the statistics also indicate that the major part of the faunal assemblage is comprised of only a few artiodactyl species, including all the cervids (sika deer, muntjac and sambar), water buffalos, and pigs. Altogether they represent more than 90% of the overall NISP. The predominant species will be analysed one by one in the following section.

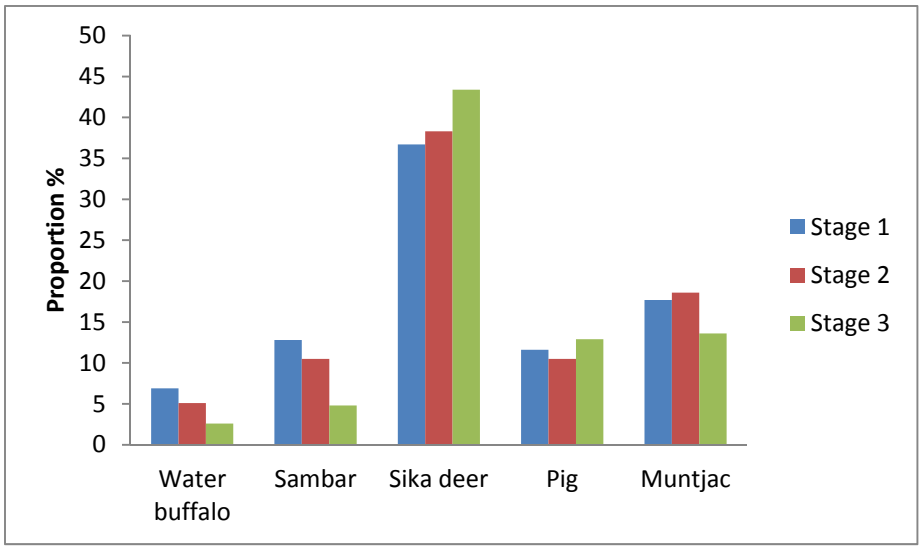


Figure 7.3 Proportional change through time of the main food mammals, calculated by NISP. The mammals are arranged in an order of average body size.

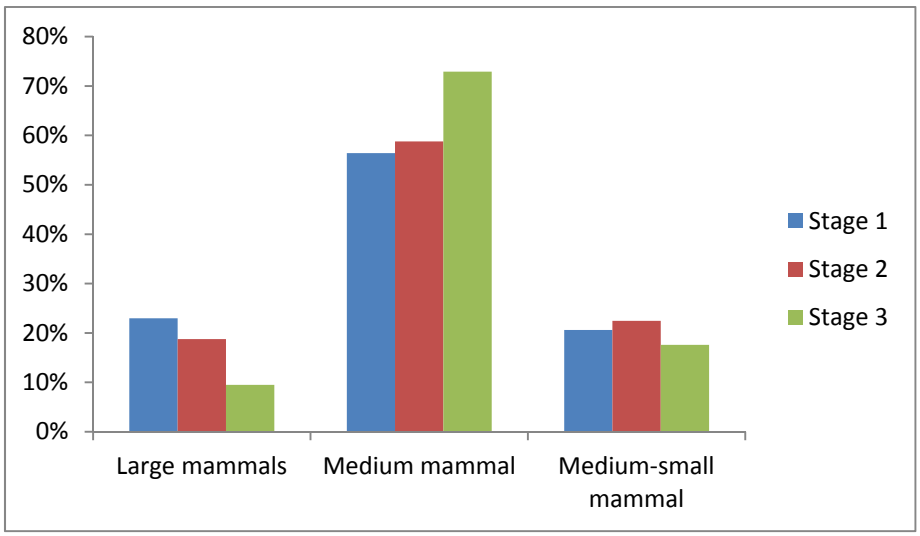


Figure 7.4 Proportional change of the main food mammals classified by average body size.

Table 7.2 Diversity (*H'*) and equitability (*V'*) of the main food species from Tianluoshan, and the change through time.

Stage 1	**NISP**	p_i	$\text{Log}_e p_i$	$p_i \text{Log}_e p_i$	***H'***	***V'***
Water buffalo	64	0.0804	-2.5207	-0.2027	0.2027	0.1259
Sambar	119	0.1495	-1.9005	-0.2841		
Sika deer	341	0.4284	-0.8477	-0.3632		
Pig	108	0.1357	-1.9975	-0.2710		
Muntjac	164	0.2060	-1.5797	-0.3255		
Stage 2	**NISP**	p_i	$\text{Log}_e p_i$	$p_i \text{Log}_e p_i$	***H'***	***V'***
Water buffalo	214	0.0610	-2.7963	-0.1707	0.1707	0.1060
Sambar	444	0.1266	-2.0664	-0.2617		
Sika deer	1618	0.4615	-0.7733	-0.3569		
Pig	443	0.1264	-2.0687	-0.2614		
Muntjac	787	0.2245	-1.4940	-0.3354		
Stage 3	**NISP**	p_i	$\text{Log}_e p_i$	$p_i \text{Log}_e p_i$	***H'***	***V'***
Water buffalo	31	0.0331	-3.4087	-0.1128	0.1128	0.0701
Sambar	58	0.0619	-2.7822	-0.1722		
Sika deer	527	0.5624	-0.5755	-0.3237		
Pig	156	0.1665	-1.7928	-0.2985		
Muntjac	165	0.1762	-1.7367	-0.3058		

Key to abbreviations: *pi* is the relative abundance of the *i*th taxon within the sample. Shannon-Weaver function is $H' = -\sum(pi)(\text{Log}_e pi)$. Equitability is measured as $V' = H' / \text{Log}_e S$; the number of species in the assemblage is *S*.

The taxonomic analysis implies that a few animal species were more extensively hunted and consumed than others, and they are the important food animals; they include water buffalo, sambar, sika deer, pig, and muntjac. Figure 7.3 summarizes the proportional change of the five predominant food mammals through the time; all of them are artiodactyl. The proportion of large-sized mammals, i.e. water buffalo and sambar, drops gradually from Stage 1 to Stage 3. The proportion of muntjac, a medium-small ungulate stays stable first, and decreases in Stage 3. The proportion of sika deer increases, especially in Stage 3 when it rises by about 5%. The percentage of pig fluctuates between 10% and 13%, and reaches its highest number in Stage 3. In general, the shift indicates a pattern in exploiting the ungulates: the use of large mammals significantly drops from 22% to less than 10%; meanwhile, the proportion

of medium-sized mammals increases from 57% to 73%. Overall, the change is more prominent in Stage 3, i.e. the late Hemudu Period (Figure 7.4).

The diversity and equitability of the five major species also suggest high selectivity on the food animals. From Stage 1 to Stage 3, the value of both Shannon-Weaver function and equitability show a trend of decline (Table 7.2), indicating a high proportion of a few taxa in the sample rather than an even distribution. The Tianluoshan people tend to give up large mammals and rely more on the medium sized mammals such as sika deer and pig. The reasons for this phenomenon shall be discussed later in this chapter.

In the next section, each of the major species will be analysed in detail before coming to the discussion of the whole faunal assemblage. The major questions include body part representation, cull patterns, and culling seasons. Although taking up a relatively small proportion, pig remains will be emphasized due to their important position in the economic subsistence across East Asia. The analysis aims to answer one question: what is the status of pig in the Hemudu Period? In contrast with pig and other domestic animals, wild animals are only briefly discussed despite the fact that they play a more important part in the subsistence most of the time. In this chapter, two of the main wild animals, sika deer and muntjac are analysed in order to discuss the hunting strategies; the objectives include body part representation and reconstruction of their culling patterns.

7.2 Pig

Amongst all the animals, pig has always been paid extra attention in Chinese zooarchaeology. For one reason, pig is a widely distributed animal and pig remains

have been commonly uncovered from archaeological sites across China. For another, domestication has been a key question in Chinese archaeology; therefore, as one of the earliest domesticated animal, pig has been extensively studied in the past decades. Bio-molecular research indicates that East Asia is one of the multiple centres for pig domestication, and at least one domestication event occurred (Larson et al., 2005). Based on the study of various archaeological materials, archaeologists suggest that pigs were domesticated early in China, probably at about 10,000 years ago (Yuan and Flad, 2002).

Yuan and colleagues (Yuan and Yang, 2004, Luo, 2007) suggest that pigs in the lower Yangtze River region have been domesticated since at least 8,000 years ago, based on their research on the Kuahuqiao site (6,000 – 5,000 BC, also see Chapter 2). It is commonly believed that the pig domestication in the Hemudu Period (5,000 – 4,000 BC) made more significant progress than the previous period, and possibly became an important element in this 'sophisticated agriculture society'. There is no doubt that domestication develops greatly in the Songze and Liangzhu Periods after the decline of Hemudu Culture.

However, the materials from Tianluoshan do not tally with this view. As presented in Section 7.1, the relative proportion of pig is much lower than expected, making it only fourth in importance as an animal resource. This proportion is quite low for a domestic animal. Apparently the process of pig domestication in the lower Yangtze River, possibly in a much broader area as well, should be revisited with an open mind.

This section aims to answer one question: are the pigs at Tianluoshan wild or

domesticated? Archaeologists have developed several criteria for distinguishing domestic animals from wild ones, including metrical methods, cull patterns, relative species abundance, and pathologies. These methods shall be used to examine the Tianluoshan pig remains, and thus to identify the status of pigs.

7.2.1 Body part representation

Analyses of body part representation can be used to study topics such as carcass transport, food processing, season of site occupation, and the differentiation of kill sites and settlement sites (Binford, 1984, Bunn et al., 1986, Purdue et al., 1989, Speth, 1983). However, the survivorship of skeletal elements is intensely influenced by natural factors and human activities, such as bone density, food processing methods, post-depositional changes, retrieval methods, and a series of other taphonomic processes (Lyman, 1984, 1994, Marshall and Pilgram, 1991, O'Connell et al., 1988). In this thesis this method is employed to reveal the survivorship of different skeletal parts *in situ*, and to interpret the reasons which lead to this result. Skeletal parts of pigs have been identified and recorded during the prime data collection procedure, and 27 skeletal parts, such as axis, mandible, humerus proximal end, etc., covering the whole skeleton, are used for analysis. The minimum number of elements (MNE) and expected number of each part can be calculated from the prime data, and then the body part presentation can be calculated accordingly. The results of all three Tianluoshan stages are shown in Figure 7.5.

In general, the body part representation does not differentiate between stages. All skeletal parts, from head to toe, are present at the site, suggesting that both processing and consuming procedures were undertaken at the site. Mandibles and

limb bones are generally well preserved; meanwhile, phalanx, metapodials, cranial bones, vertebra, patella, and the proximal end of tibia are less well preserved. The differentiation is more prominent at Stage 3 (Figure 7.5).

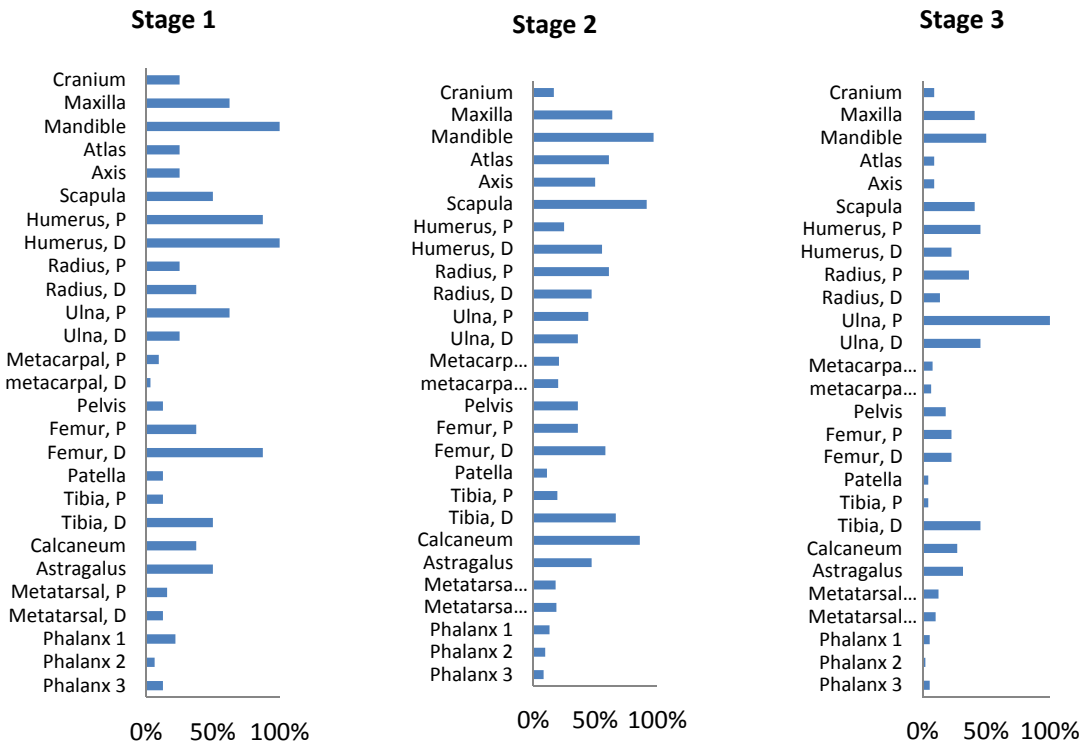


Figure 7.5 Body part representation of pigs at Tianluoshan

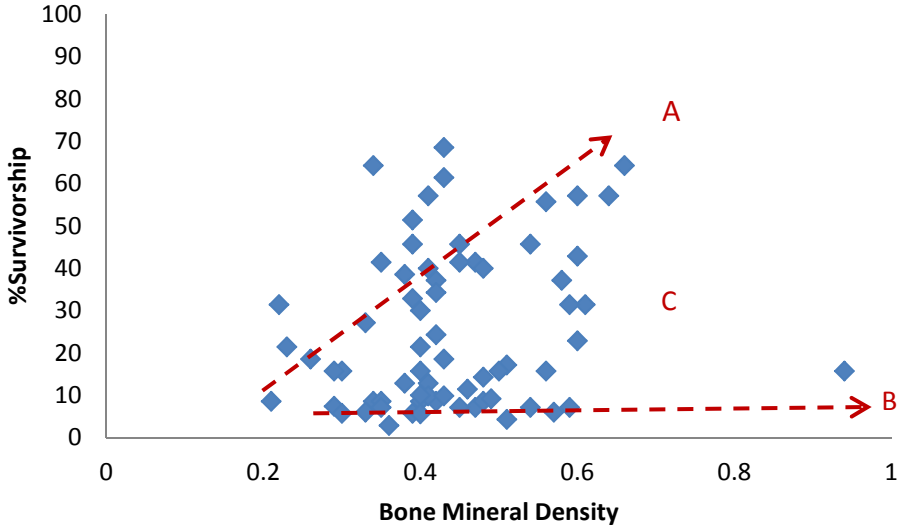


Figure 7.6 Scatterplot of survivorship of pig skeleton parts from Tinluoshan against pig bone mineral density values, based on Ioannidou's (2003) data.

Many factors can lead to survivorship differentiation between skeletal parts, but one of the most important factors throughout the long term taphonomic process is the natural property of bone. The potential resistance of bones to consumers and post-depositional processes is conditioned partly by the structural density of bone tissues. There have been several ways to measure bone mineral density. The earlier attempts measured bone density using the measurements of bone mass and volume (Behrensmeyer, 1978, Binford and Bertram, 1977, Brain, 1969, 1976). This method calculates the average value of bone density, and is less accurate. Dissimilar density values have been produced for similar bone fragments of a single species in previous research (Lyman, 1984). The application of advanced technology, such as photon densitometry (Lyman, 1984) and computed tomography (Lam et al., 1998, 1999) makes the measurement of bone density accurate, and reveals inter- and intra-taxonomic variability. The measurements of pig and deer bone density are much lower than those of cattle and sheep/goat. Ioannidou's (2003) data are used for discussing the relation between pig bone mineral density and the survivorship of different skeletal parts.

Figure 7.6 does not show a density mediated attrition. Two trends can be detected in the bone survivorship against bone mineral density scatterplot. On one hand, bone density and survivorship are positively related (trend 'A'), indicating that bones with high density are more likely to be preserved. On the other hand, bond density plays a minor influence on many skeletal parts (trend 'B'). Even skeletal parts with very high bone density, e.g. ischiums, have a low survivorship rate. In addition, there are a few data distributed between the main streams of the two trends (area

'C'). I will attempt to interpret the pig bones survivorship by comparing bone mineral density with body part representation.

According to Iaonnidou's research, the high density (above 0.5) bone parts include scapula neck, proximal radius and shaft, ilium, ischium, femur shaft, tibia shaft, metacarpal Ⅳ, calcaneus, and phalanx Ⅱ; the highest density is detected on ischium (code 'IS1'). In general, bones with high density are more resistant to the external effects. However, most of these bones parts, except for scapula neck, ilium, and proximal radius, display a low frequency in body part representation. Their under-presentation is due to different reasons. The shafts of radius, femur and tibia are less common presented at sites than the proximal and distal ends. They are often broken for marrow or during natural taphonomic processes, and the splinters are unidentifiable. Although ischium is the densest bone part in pig's skeleton, its thin structure makes it susceptible to certain forces. Small bones such as calcaneus, metapodials, and phalanxes are less nutrient, and are not ideal material for bone working. The underrepresentation of these bones is likely caused by the retrieval method of hand picking. As is described in Chapter 4, although wet sieving was used for collecting fish remains, mammal remains were primarily retrieved by hand collecting. From the excavation in 2011, sieving was applied more thoroughly, and a skim of the mammal bones reveals that the amount of small bones less than 5 cm increases significantly.

7.2.2 Morphometric data

Size reduction is generally detected in domesticated animals in comparison to their wild ancestors, and thus the size differentiation is commonly used as a method

to identify domestic animals (Flannery, 1983, Stampfli, 1983). The lower third molar (M3) may be the most frequently used element in studies, and a sequence of M3 size from Neolithic and Bronze age sites across China has been established in previous research (Luo, 2007). Compared to teeth, the size changes of post-cranial bones are less well studied in China, partly because of the small sample size and poor preservation in the early stages of the domestication process. The log size index proposed by Meadow (1999) will be employed to overcome the weakness of the small sample size.

In this section, the morphometric data of both the lower M_3 and post-cranial skeletal parts are presented, in order to show explicitly whether there is any size change between the Tianluoshan samples and wild boars. Archaeological specimens from the lower Yangtze River sites are also used for comparison.

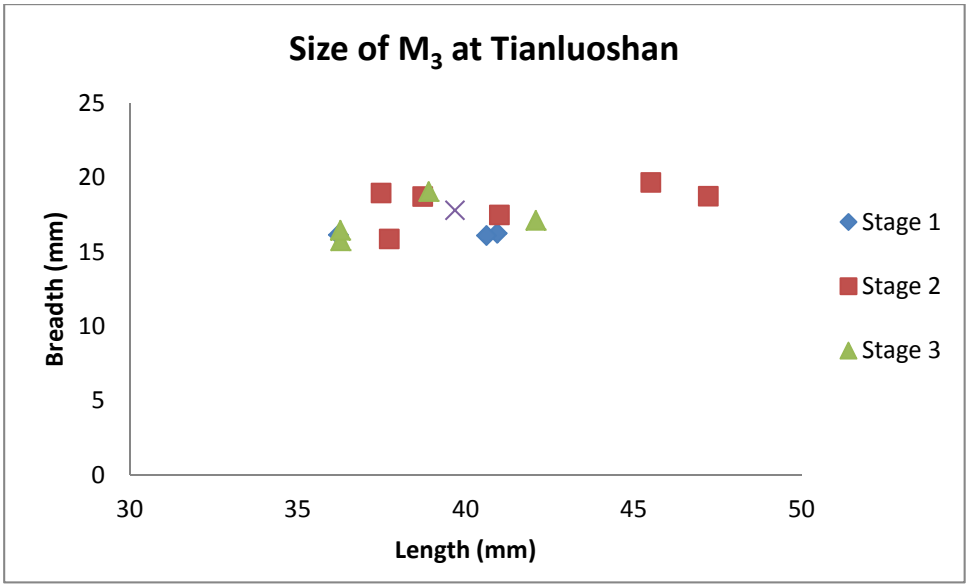


Figure 7.7 Morphometric data of lower M_3 of pigs, N=13. The measurement of a modern wild boar specimen is plotted.

7.2.2.1 The metrical analysis of lower M3

The length and breadth of the lower third molar are taken following the

guidelines of von den Driesch (1976). Restricted by sample size, only 13 measurements can be taken from the entire site, three of them are from Stage 1, seven from Stage 2, and four from Stage 3. The data are plotted in Figure 7.7 (Appendix 1), as well as the measurements from a modern wild specimen from the reference collection in Henan Provincial Institute of Archaeology.

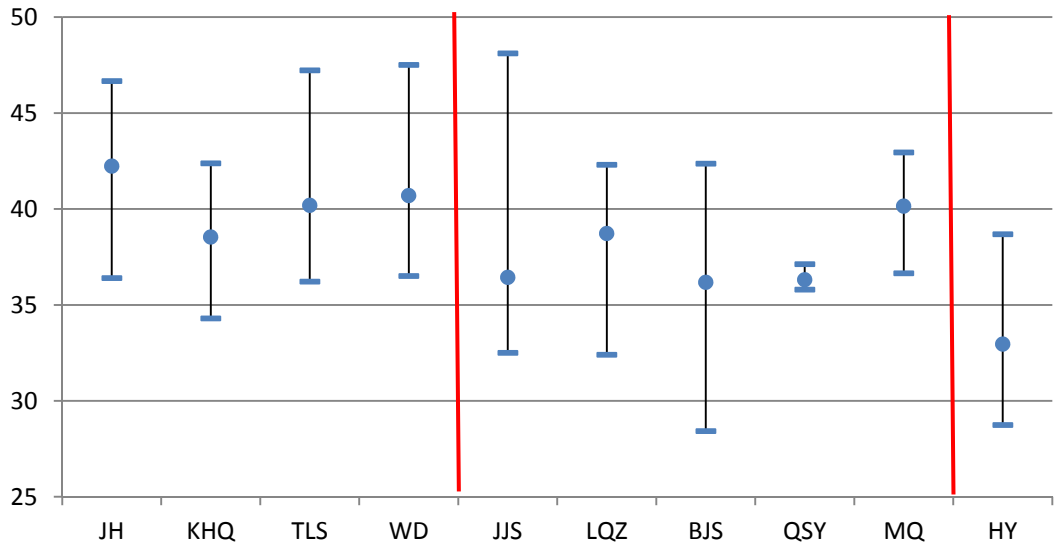


Figure 7.8 Lower M_3 length of pigs from sites in the Southeast China of different period. In the Central Plain: Jiahu (JH, about 7,000 – 5,000 BC). In the Lower Yangtze River region, from the earliest to the latest: Kuahuqiao (KHQ, 6,200 – 5,000 BC), Tianluoshan (TLS, 5,000 – 4,000 BC), Weidun (WD, approximately 4,000 BC), Jiangjiashan (JJS, 3,900 – 3,700 BC), Longqiuzhuang (LQZ, 4,600 – 3,000 BC), Bianjiashan (BJS, 2,800 – 2,300 BC), Qianshanyang (QSY, 2,400 – 2,000 BC), Maqiao (MQ, 1,900 - 1200 BC) and Heying (HY, approximately 1,000 BC). is located in the Huai River, adjacent to the north bank of Lower Yangtze River. The dates of sites and measurements are summarized from published reports and research papers. Detailed measurement data are listed in Appendix 2.

The Tianluoshan specimens are quite large, with an average length of 40.2mm. The length of M_3 covers a wide range, approximately from 36 mm to 47 mm. A review of the size range of wild boars will help to interpret the dataset. Previous research on modern Eurasia wild boars shows a wide range of the lower M_3 length, approximately from 36 mm to 50 mm, indicating great variation between individuals

(Flannery, 1983, Payne and Bull, 1988, Hongo and Meadow, 1998, Luo, 2007). The Tianluoshan specimens fall exactly into the length range.

In order to view the M_3 size of Tianluoshan pigs under a broader background, published data from nine sites spanning the early Neolithic to Bronze Age are brought for comparison (Figure 7.8). Considering the geographic variability of size between different breeds (Rowley-Conwy et al., 2012, Luo, 2007, P19), the referencing specimens are specifically chosen from sites in the Yangtze River and Huai River region, which share similar environmental and climatic conditions.

Range and mean value of lower M_3 lengths are illustrated in Figure 7.8. In general, the measurements show a size reduction with strong fluctuation through time. According to size changing, the sequence can be divided into three phases. The first phase is from the end of the early Neolithic to late Neolithic (7,000 – 4.000 BC, date and classification see Chapter 2), sites including Jiahu, Kuahuqiao, Tianluoshan, and Weidun (Figure 7.8). During this phase, the size of lower M3 is quite large, within the same range of Tianluoshan specimens (approx. 36 - 47mm); and the mean value is about 40mm or more. The measurements of the Kuahuqiao specimens are smaller than the other three sites, but it is possibly relevant to the method of taking measurements. The report does not specifically refer the measuring points on M_3, the research states (personal communication) the length of lower M_3 is possibly taken on the occlusive surface, which is smaller than the measurement taken at the base of tooth crown (Von den Driesch, 1976). Phase two is generally from the epi-Neolithic until the final Neolithic (4,000 – 2,000 BC), including Jiangjiashan, Longqiuzhuang, Bianjiashan, Qianshanyang, and Maqiao. During this phase, the

mean values of lower M_3 lengths reduce by 3 – 5 mm, but the change in size range appears later than the change of mean value. For instance, the size of the Jiangjiashan (Majiabang Culture) specimens shows great variability, ranging from 33 to 48 mm. The minimum value drops to the average phase two standard, but the maximum value stays at the phase one range, possibly indicating the exploitation of both wild and domestic pigs. Thus, Jiangjiashan can be seen as a transition pattern in the process of M_3 size reduction. Maqiao, in the final Neolithic, is a special case during the development of archaeological cultures in the lower Yangtze River region (see Chapter 2). It rose after the decline of the sophisticated Liangzhu culture, and developed a simple material culture. On subsistence economy, wild artiodactyls regained predominance in Maqiao Culture (Huang and Cao, 1978). Phase three is the Bronze Age, when a significant reduction of size range and mean value occur.

7.2.2.2 Postcranial measurements

Restricted by small sample size, it is impossible to compare the size of a single postcranial bone with wild boar or specimens from other archaeological sites. Under this circumstance, the LSI technique (Logarithm Size Index) developed by Meadow is employed to investigate variability in pig size through time, and thus assist in identifying the status of Tianluoshan pigs. By converting all the measurements into logarithms, this technique graphically compares the relative rather than the absolute dimensions of a number of animals or groups of animals (Meadow, 1999). The equation for generating logarithms can be expressed as:

$$\mathrm{LSI} = \log x - \log m = \log(x/m)$$

in which ‘x’ represent the measurement of the target specimen, and ‘m’ is the

corresponding measurement of the 'standard animal' or 'standard population' from which mean dimensions are calculated. According to the equation, the measurements of the 'standard animal' refer to the origin of the coordinates on the axis; specimens larger than the standard have positive values, and those smaller than the standard get negative values. The greater the size difference, the larger the absolute value of the LSI. As the LSI technique converts measurements into digital indices, the measurements of different skeletal parts can be demonstrated on a single axis. It enlarges the sample size, so that the whole skeleton can be used for discussing size differences.

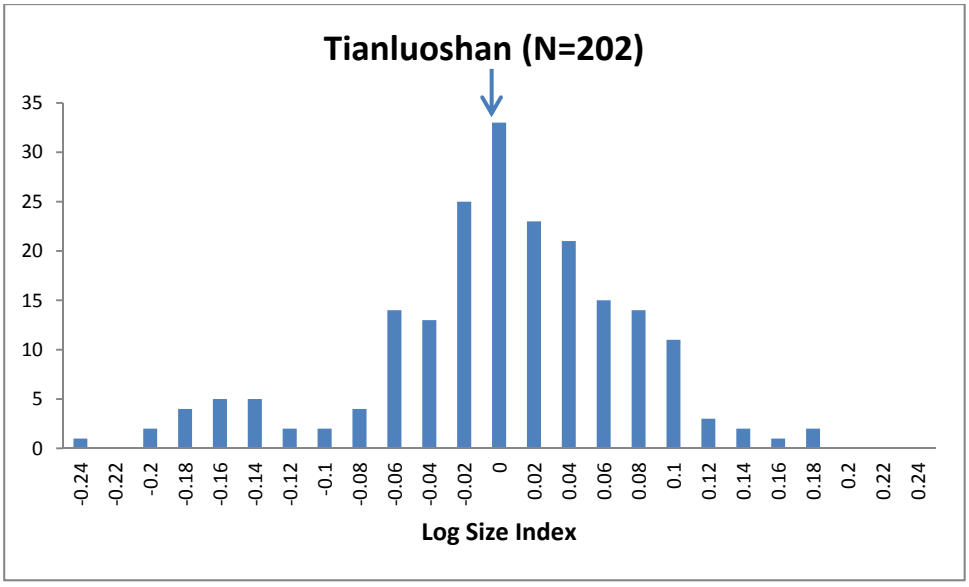


Figure 7.9 Log size index data for pig postcranial bones at Tianluoshan.

In this study, a female adult wild boar from the modern reference collection in Henan Provincial Institute of Archaeology, collected in Quzhou County, Zhejiang Province, is used as the 'standard animal'. Measurements of skeletal parts are taken with the permission of Dr. Xiaolin Ma from the Henan institute. The logarithms of the postcranial measurements are calculated using the LSI method, and the distributional frequency is displayed in Figure 7.9. The medians are also plotted. It appears that the

distribution of Tianluoshan pig LSI falls into the size range of modern wild boar.

The basic assumption underlying this method is that the body proportions of the archaeological specimens were the same, or at least similar to, the body proportions of the standard animal (Meadow, 1999). However, body and bones sizes are influenced by several factors. Climate has significant influence on body size as is demonstrated by Allen's and Bergmann's Rules. It has been demonstrated that wild boars in colder climates were larger than those in warmer climates (Davis, 1981, Davis, 1987, Rowley-Conwy et al., 2012). The 'standard animal' in this research is collected from an adjacent area in the Lower Yangtze River region, and this may be an advantage for this study. Nevertheless, as pointed out by Meadow himself, modern wild forms may differ in proportions and in degree of variability from their presumed ancestors in the same region (Meadow, 1999). On the other hand, the measurements within a population vary due to age (allometric growth) and sex (dimorphism) (Payne and Bull, 1988); therefore, the standard animal in this case study may represent the smaller range of the entire size variety.

In order to interpret the size range and change of Tianluoshan pig, the data from another two sites, Kuahuqiao (6,200 – 5,000 BC) and Bianjiashan (2,800 – 2,300 BC) are brought in for comparison. The measurements from Kuahuqiao are summarized from the published report, in which only maximum, minimum, and mean value are recorded (Yuan and Yang, 2004), so that the LSI values group in the middle and at both ends of the distribution; but the size range is not influenced by the data bias (Figure 7.10). The Bianjiashan data are from my master's dissertation, in which domestic pig remains are identified after a series of thorough examinations of

morphometric data, cull pattern, pathologies (LEH), and cultural phenomena (Zhang, 2009). The Tianluoshan data are also presented separately by stage. Although the sample sizes of Stage 1 and 3 are small, the application of the LSI technique has already enlarged the sample size significantly, compared to that of teeth specimens. The median of each sample is plotted to indicate the change of its location.

Restricted by sample size, the size ranges of Stage 1 and 3 are smaller compared to the typical Stage 2 and the other two sites. In general, the size range does not change much from Kuahuqiao to Tianluoshan. Size reduction becomes prominent at Bianjiashan site (Liangzhu Culture). The medians also indicate a tendency of size reduction from Kuahuqiao (Middle Neolithic) to Bianjiashan (Final Neolithic): from Middle to Late Neolithic the change is minor, but accelerates afterwards. This change accords with the size reduction process of the lower M_3.

The histograms in Figure 7.10 show a common characteristic that large-sized individuals are predominant in the assemblage. It may be caused by several reasons. First, some of the small-sized specimens are missed during retrieval. Payne and Bull's (1988) research suggests that body size and age are positively related; therefore, some of the small-sized bones belonging to the young individuals are unfused, and might not have been collected during excavation. Second, cultural preference may have played an important part in the size composition, especially in the Liangzhu Period. The strong canines of male pigs are favourable materials for making accessories, so the Liangzhu people tended to save pigs to an older age to collect fully grown canines.

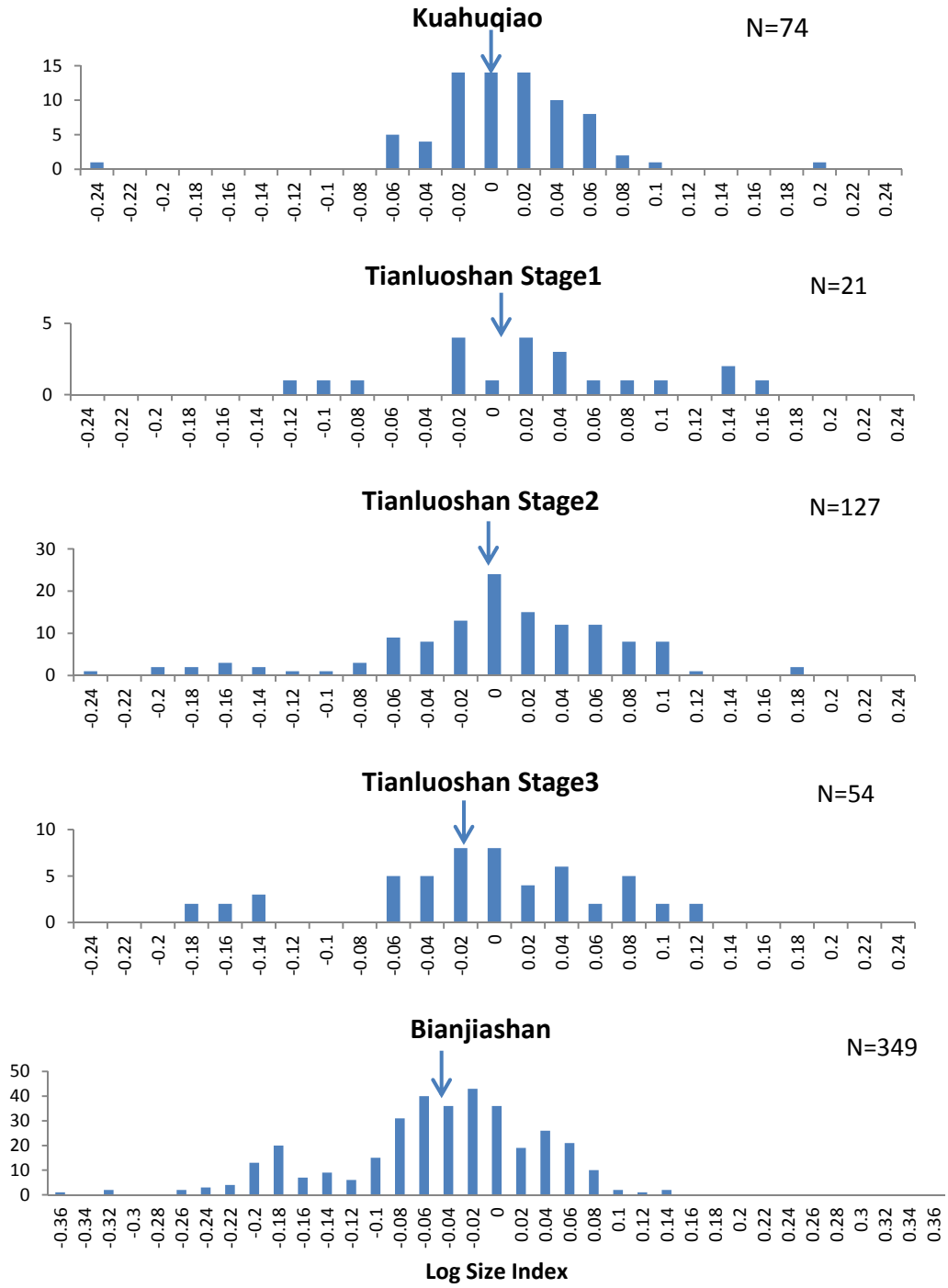


Figure 7.10 Summary of log size index for specimens from Kuahuqiao (N=74), Tianluoshan (TLS, N=202) and Bianjiashan (BJS, N=349), showing the frequencies of indices falling into the various 0.02 intervals. The arrows refer to the medians of indices.

7.2.3 Cull patterns of Tianluoshan pig

Kill-off pattern of animals has been commonly used to investigate domestication of animals, based on the model of ideal slaughter schedule. Slaughter of

domesticated animals can be designed as to get the maximum yield, while the kill-off of wild animals cannot be controlled as domestic animals. The ideal slaughter schedule varies between taxa, depending on how the animal is exploited. When animals are raised for providing meat, individuals may be slaughtered at a relatively young age when they nearly reach the adult size and growth begins to slow down. On the other hands, animals that are kept for secondary products may be killed at an older age.

The approximate age at death can be determined from the stage of epiphyseal fusion and from the eruption and wear of teeth. In this section, the cull pattern of pigs will be reconstructed from epiphyseal fusion and teeth. Due to the small sample size of pig remains, all individual from three stages are calculated together.

7.2.3.1 Fusion ageing

The epiphyseal fusion of skeletal parts occurs at specific times during an animal's life, thus providing evidence to estimate the age from the state of epiphyseal fusion (unfused, fusing and fused).

According to the epiphyseal fusion sequence of pig presented by Silver (1969) and Bull and Payne (1982), there are a few fusion events during the life of the animal. The first happen before birth, and include the proximal epiphyses of metapodials and the distal ends of first and second phalanges. The second fusion event - the first after birth – occurs at around 12 months of age, on the tuber scapula, acetabulum, distal humerus, proximal radius and proximal phalanx 2. The third fusion event occurs at about 24 months of age, on distal tibia, distal metapodial and proximal phalanx 1, and followed by the fusion of distal fibula and tuber calcaneus at about 30 months of

age. The last fusion event ends between 36 to 42 months of age, including a group of late fusing epiphyses such as proximal humerus, proximal and distal of ulna, distal radius, proximal and distal femur, proximal tibia and proximal fibula. Therefore, the post cranial parts of pigs are grouped into three phases according to their fusion time, and the corresponding data of three stages at Tianluoshan are presented (details see Table 7.3).

Table 7.3 State of epiphyseal fusion and survivorship for pigs from Tianluoshan.

Phase	Epiphyses	Fusion age	Stage 1			Stage 2			Stage 3		
			Fused	fusing	unfused	Fused	fusing	unfused	Fused	fusing	unfused
Ⅰ	**scapula**	12	4	0	0	24	0	7	6	0	3
	pelvis	12	0	0	1	13	0	0	2	0	0
	humerus d	12	6	0	2	14	0	6	8	1	5
	radius p	12	2	0	0	18	0	5	6	0	0
	phalanx2 p	12	1	0	1	14	0	0	2	0	0
	subtotal	12	13	0	4	83	0	18	24	1	8
	%		**76.5%**	0	23.5%	**82.2%**	0	17.8%	**72.7%**	3.0%	24.2%
Ⅱ	**tibia d**	24	3	1	0	15	4	6	7	0	3
	fibula d	30	0	0	0	0	0	0	0	0	0
	metacarpals d	24	3	0	0	7	0	0	5	0	0
	metatarsals d	27	4	0	0	11	0	0	6	0	2
	calcaneum	24-30	2	0	1	12	0	0	2	0	5
	phalanx1 p	24	5	1	0	14	0	0	4	0	0
	subtotal	24-30	17	2	1	59	4	6	24	0	10
	%		**85%**	10%	5%	**85.5%**	5.8%	8.7%	**70.6%**	0	**29.4%**
Ⅲ	**humerus p**	42	0	0	7	3	0	0	0	0	3
	radius d	42	2	0	1	2	0	14	0	0	3
	ulna p	36-42	4	4	4	8	0	0	9	0	9
	ulna d	36-42	0	0	1	2	0	0	1	0	0
	femur p	42	1	0	2	4	0	10	1	0	4
	femur d	42	1	0	6	6	0	16	1	0	4
	tibia p	42	0	0	1	1	2	5	0	0	1
	fibula p	42	0	0	0	0	0	0	0	0	0
	subtotal	36-42	8	4	22	26	2	45	12	0	24
	%		**23.5%**	11.8%	64.7%	**35.6%**	2.7%	61.6%	**33.3%**	0	66.7%

To summarize the statistic in Table 7.3, through all three stages, over 70% of pigs have survived the first year of life, and only 1/4 or less were killed under one year old. The survivorship of phase 2 is still high, ranging from 70% to 85%. There is a sudden drop of the survivorship between phase 2 and phase 3, suggesting that massive slaughter happened to the pigs age between 24 and 42 months old. The survivorship curved can be viewed in Figure 7.11.

Both statistics and chart show little difference between Stage 1 and Stage 2 at Tianluoshan; but a gap appears between the survivorship curve of Stage 3 and the other two. Going back to the data in Table 7.3, it is noticeable that the unfused epiphyses rate of phase Ⅱ in Stage 3 is much higher than the rate in Stage 1 and 2, meaning that more juvenile pigs (younger than 24 months old) were slaughtered in the latest period of Tianluoshan. However, there are still a significantly high percentage of older individuals.

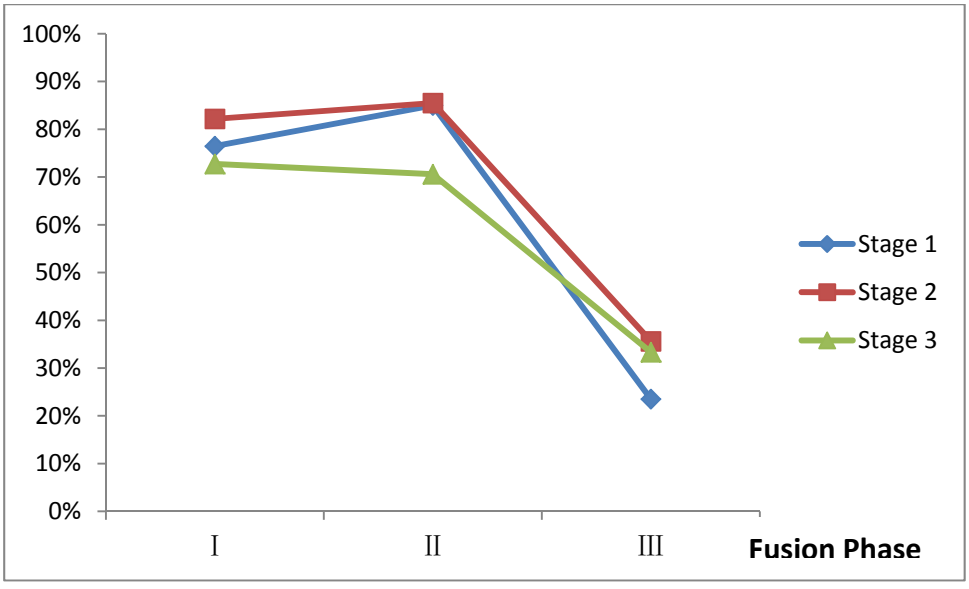


Figure 7.11 Survivorship curve of pigs from three stages of Tianluoshan.

Table 7.4 Tooth eruption and wear stages for *Sus*, reproduced from Hongo and Meadow (2000).

Wear phase	**Age**	**Tooth wear stages (after Grant 1982)**									
		dp4	**dp other**	**di**	**M1**	**M2**	**M3**	**P2, P3**	**P4**	**I**	**C**
Ⅰ	Newborn	a, b, c	erupting, slight	erupting, slight							
Ⅱ M1 erupting	Up to ca. 6 months	d	moderate		erupting, a, b						
Ⅲ M2 erupting	ca. 6-12 months	e, f, g, h, I, j, k, l	moderate, heavy	moderate, heavy	c, d, e	erupting, a, b	unerupted			I3 erupting	erupting
Ⅳ P4 erupting	ca. 12-18 months				f, g	c, d	erupting	erupting, slight	a, b, c	I1 erupting	
Ⅴ M3 erupting	ca. 18-24 months				h	e	a, b	moderate	d, e	I2 erupting	
Ⅵ	Over 24 months but not old				j, k	f, g, h	c, d, e	heavy	f	heavy	
Ⅶ	Old				l, m, n	j, k	f, g, h, j		g, h		

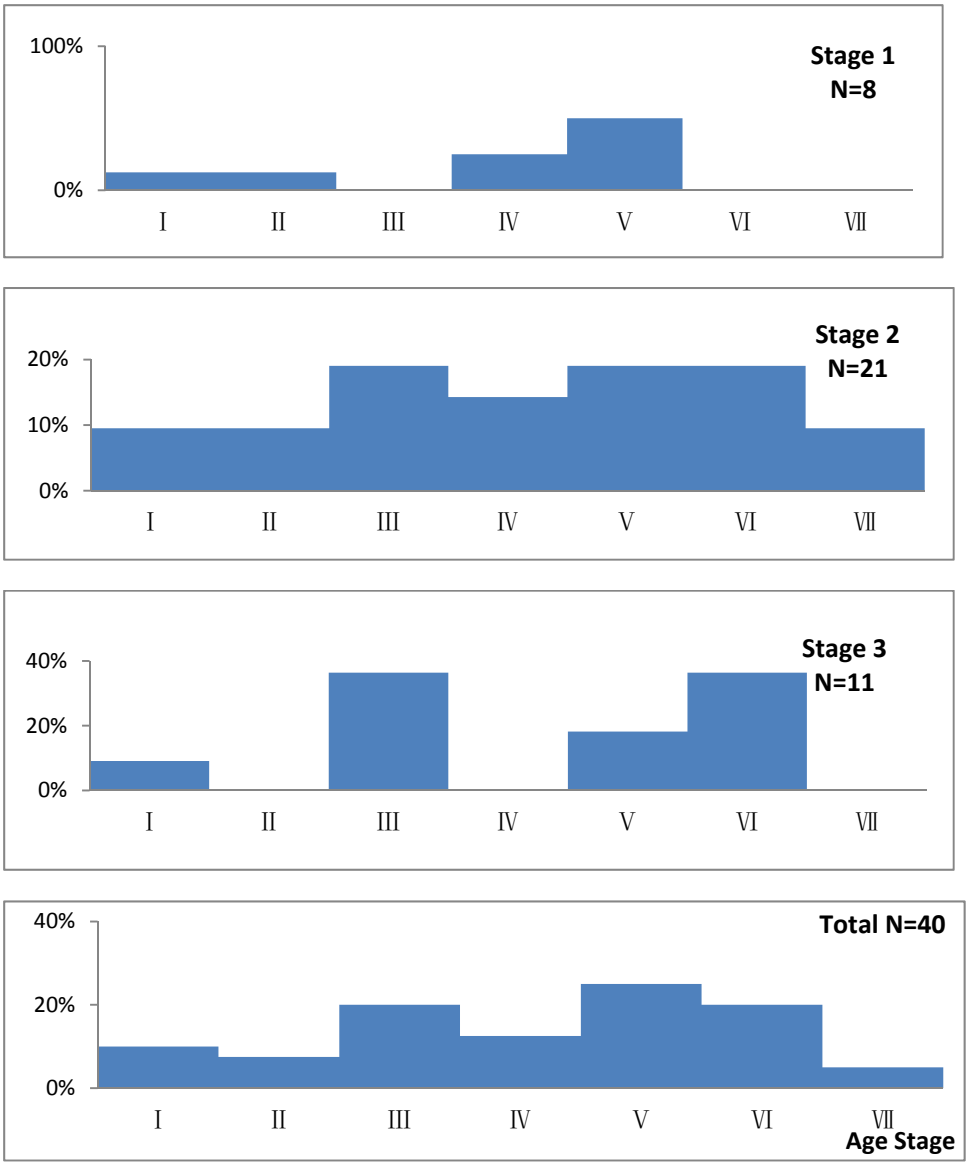


Figure 7.12 Cull pattern for pigs from Tianluoshan in each stage and the total assemblage. The age groups are classified after Hongo and Meadow (2000).

7.2.3.2 Dental ageing

In the ageing process, tooth eruption and wear data can be used with great confidence. Bull and Payne (1982) have presented the eruption sequence of pigs and wild boar. Grant's (1982) TWS (Tooth Wear Stage) coding system is used to record the eruption and wear of teeth, and to determine the age of the individual. Unfortunately, the sample size from Tianluoshan is small, making it impossible to

create a detailed cull pattern using Grant's mandible wear score method. An alternative method separates a pig's life into a few phases based on teeth eruption and wear, as Hongo and Meadow did in their research (2000). This ageing system shall be applied to the Tianluoshan pigs.

During analysis it is noticable that Hongo and Meadow's method has its imperfection which may cause serious misunderstanding. Table 6 in Hongo and Meadow (2000) lists seven age phases which are defined by tooth eruption and wear. For phase III (about 6 – 12 months old), the wear stage of M1 according to Grant's coding system is 'c', 'd', or 'e', and M2 erupting or with a wear stage of 'a' or 'b'. For phase V (about 18 – 24 months old), the wear stage of M1 is 'f', 'g', or 'h', and the wear stage of M2 is 'c', 'd', or 'e'. We can see that the wear of M1 and M2 in phase IV is not used; only the eruption and wear of premolars and incisors are described. Statistically, phase IV lasts for about 6 months (12 – 18 months old), so it is impossible that no wear happens to the M1 and M2 during this period. Therefore, the research papers about tooth eruption and wear (Grant, 1982, Bull and Payne, 1982, Silver, 1969) have been reviewed, and the TWS has been relocated to different phases to make it consistent (Table 7.4).

A total number of 40 mandibles from Tianluoshan are used for ageing; among them, 8 are from Stage 1, 21 from Stage 2, and 11 from Stage 3 (Appendix 1). Due to small sample size, the kill-off pattern of the complete sample is included with the staged analysis (Figure 7.12). The histograms indicate that pigs at varied age stages are slaughtered, and approximately half the slaughter occurs to individuals aged

between 6 and 24 months. There are still a considerate number of older individuals. Although there are not many specimens in each stage, the results imply that more young pigs aged about 12 months are slaughtered in Stage 2 and 3 compared to Stage 1.

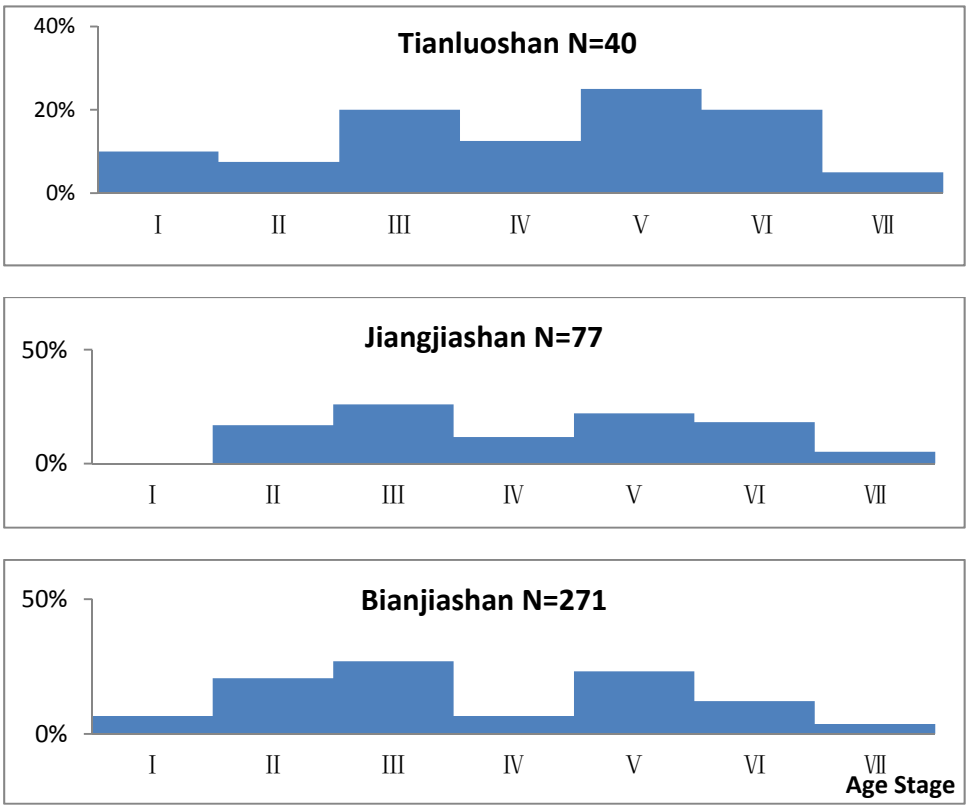


Figure 7.13 A comparison of Tianluoshan (5,000 – 4,000 BC) cull pattern with two sequential sites in the lower Yangtze River region, Jiangjiashan (3,900 – 3,700 BC) and Bianjiashan (2,800 – 2,300 BC). The data of pig remains from Jiangjiashan and Bianjiashan are from previous research.

A comparison with the cull patterns from other sites in this region will help to define the status of pigs and to understand the changes through time. In this case, the data from Kuahuqiao (Kuahuqiao Culture, 6,200 – 5,000 BC), Jiangjiashan (Majiabang and Songze Culture, 3,900 – 3,700 BC), and Bianjiashan (Liangzhu Culture, 2,800 – 2,300 BC) are used for reference. The age of 26 individuals from Kuahuqiao are identified from teeth eruption and wear. Instead of presenting the

entire culling structure, the researchers use 2.5 years as a boundary between youngsters and adults, and give the proportions of each group. Altogether 15 individuals belong to the adult group, which is equivalent to wear phase Ⅵ and Ⅶ, taking up 57.7% of the MNI. As the Kuahuqiao site was occupied for quite a long time, the researchers also notice an increase of the proportion of youngsters from the early phase (12.5%) through the middle phase (42.9%) to the late phase (54.5%). Despite the adult-predominant cull pattern and small sample size, the specimens are identified as domestic pigs based on dental crowding, the increasing proportion of individuals younger than 2.5 years old, and the smaller lower M_3 (Yuan and Yang, 2004). The cull patterns of Jiangjiashan and Bianjiashan are presented in Figure 7.13. Compared to the cull pattern for Tianluoshan, the proportion of wear phase Ⅲ at Jiangjiashan and Bianjiashan increases significantly, whilst wear phase Ⅴ declines, indicating a clear tendency towards killing more young individuals.

In general, by placing Tianluoshan in the Neolithic cultural sequence, the cull patterns show a gradual shift to killing young pigs instead of adults from the middle Neolithic to final Neolithic. The data indicate that the major change might happen at 4,000 to 3,500 BC, approximately during the Songze period, for example, at the Majiabang site. The Hemudu culture is just before this major shift happens; the research on the Hemudu culture can help to interpret the change of cull patterns in the lower Yangtze River region during the Neolithic.

7.2.4 Discussion: the status of pig

The pig remains from Tianluoshan are studied from all aspects to solve the mystery of the status of pig, including proportional analysis, morphometric study, cull

pattern reconstruction, and pathological observation. Statistics from a sequence of several sites are brought in for comparison, in order to show the change through time, and thus to interpret the process of pig domestication in the lower Yangtze River region.

The relative proportions within the Tianluoshan mammalian fauna indicate that pig was one of the major food mammals at the site, but obviously less important than the cervids (see Figure 7.1, Figure 7.3, Figure 7.4). Its proportion barely fluctuated throughout the Hemudu period, between 10.5% and 12.9% (Figure 7.1), possibly implying it was a stable food resource.

Although the measurable sample size is small, the M_3 metric data show a wide distribution of M_3 length which falls into the range of modern wild boars. By placing the Tianluoshan data in the regional chronological sequence, a gradual size reduction of M_3 is revealed, and Tianluoshan is located at the large-sized end. Postcranial measurements suggest the same trend in size change through time. Size reduction can be caused by various factors, and climatic change and domestication are possibly two of the most important ones. Size difference on M_3 has been noticed between the modern wild boar breeds in Northeast China and South China (Luo, 2007). The northeast breeds are obviously larger than those living in South China. According to the palaeo-environmental research, Tianluoshan was occupied during the mid-Holocene warm period; therefore, climate influence can be eliminated for the later size reduction. We may propose that the size reduction is probably caused by domestication.

The cull patterns reconstructed by both fusion ageing and dental ageing indicate

that the Tianluoshan pigs are mostly killed as prime-age adults. The comparison with dental ageing from some other sites in the lower Yangtze River shows a gradual shift to young individuals predominated population through time. Adults and prime-age adults take up significant proportions until the late Neolithic period, e.g. the Kuahuqiao culture (the Kuahuqiao site), the Hemudu culture (the Tianluoshan site), and the Majiabang culture (the Jiangjiashan site). A clear increase of yearlings can be observed at sites of final Neolithic, such as Bianjiashan, one of the Liangzhu culture sites.

In an attempt to find pathological evidence on the Tianluoshan pig remains, unfortunately, neither teeth crowding nor linear enamel hypoplasia (LEH) could be detected. Meanwhile, the other two reference sites, Jiangjiashan and Biajiashan, have different rates of LEHs and dental crowding recorded (Zhang, 2009). Modern wild boar populations generally have low levels of LEHs due to low incidence of the physiological stresses implicated in LEH formation (Dobney et al., 2007, Rowley-Conwy et al., 2012). The pig remains from several Chinese sites, covering a wide time span (10,550 – 750 BC), have been examined for LEHs, but the results appear to be negative to chronology unlike the data from south-west Asia and Japan (Dobney et al., 2007, Luo, 2007). Anyhow, comparing these data collected to domestic or possible domestic pigs, the frequency of LEH on Tianluoshan pigs is much lower, quite close to the wild boar population.

To sum up, judging from the criteria for distinguishing domestic pigs and wild boar, the Tianluoshan pigs are more likely from the wild boar population. By comparing the Tianluoshan data with those from the sequential sites in the same

regions, this research may help to update the current understanding about the process of pig domestication, the development of agriculture and the subsistence economy. A regular change can be observed in pig remains from the sequential sites in the lower Yangtze River region. In general, the relative proportion increases, and average size and age reduce from middle Neolithic to Bronze Age, indicating the development of domestication. Strong evidence for pig domestication occurred approximately at 3,000 – 2,500 BC judging from the current archaeological materials. This date is much later than the previous proposed that pig domestication started in early Neolithic.

The rich and easy-to-get wild resources restrained the development of pig domestication. A comparison with the subsistence economy from contemporary sites in north China will help to interpret this issue. In a greater range, the Hemudu Period is equivalent to the early phase of Yangshao culture in the Yellow River region, but display completely different pattern of subsistence. Plenty of domestic animals and plants have been distinguished from sites of Yangshao Culture; meanwhile, domestic rice is used as a supplementary resource. On the contrary, cervids have been used as a predominant resource until Bronze Age. Data analysis indicates that the survivorship of the population was barely threatened by hunting (see below).

7.2.5 Seasonality

As the Tianluoshan pigs are hunted from the wild, they can contribute to the discussion of the entire hunting strategy. In this section, the hunting seasons of pigs will be computed from their age at kill, so that in the next chapter, it can be compared with the estimated hunting, fishing, and foraging seasons and thus to

generate a subsistence schedule.

There are a variety of views about the breeding season of wild boars. Some claim that wild boars are capable of reproducing at any time during the year (Iacolina et al., 2009, Graves, 1984), while others insist that wild boars are seasonal breeding animals (Wu, 1984, Wu, 2000), but both views agree that the reproduction time is dependent on the climate which directly affect food availability. In general, wild boar in the temperate zone reproduces seasonally, for example, wild boars in northeast China usually give birth to a litter in spring, and in Wales it is at summer or autumn (Yang, 1984, Saunders, 1993). Those living in tropical and subtropical zones have a longer reproduction season, which may last from March until October; some can reproduce at any time of the year (Wu, 2000).

Summarizing from the research on modern wild boar, the Tianluoshan wild boar might breed in spring and early summer. With birth time and the age at death, the hunting seasons can be estimated accordingly. 28 individuals younger than 2-years are used for seasonality analysis. Their ages are identified as accurate as possible from teeth eruption and wear stage. The seasonality estimation is based on the assumption that the piglets were given birth in April in the Hemudu period. The results are shown in Figure 7.14.

The data suggest that wild boar hunting was practiced all year long at Tianluoshan, but more intensively in autumn. The boars killed in autumn include both yearlings and the sub-adults before their second winter. Although not included in the analysis, wild boars over 2-years old might also be hunted during this season.

The seasonal management of boar hunting reflects the hunting strategy. On one hand, the hunting season might be decided in order to maximize the yield of meat

acquisition. Like other animals, wild boar experience significant body weight fluctuation between different seasons. Their average body weight in later summer might be 40kg heavier than that in later winter. On the other hand, the hunting activity can be summarized in two different ways, tactical and strategic. Young males are usually driven from the flock before the mating season in autumn, therefore in winter the inexperienced young males would be easy targets. Strategically, wild boar would face increased hunting which lasts all year round rather than being seasonal. Strategic hunting chooses certain targets, and may involve sustainable plans to keep the wild boar population alive or even growing (Rowley-Conwy et al., 2012). Therefore, the wild boar hunting at Tianluoshan was practiced in the strategic way.

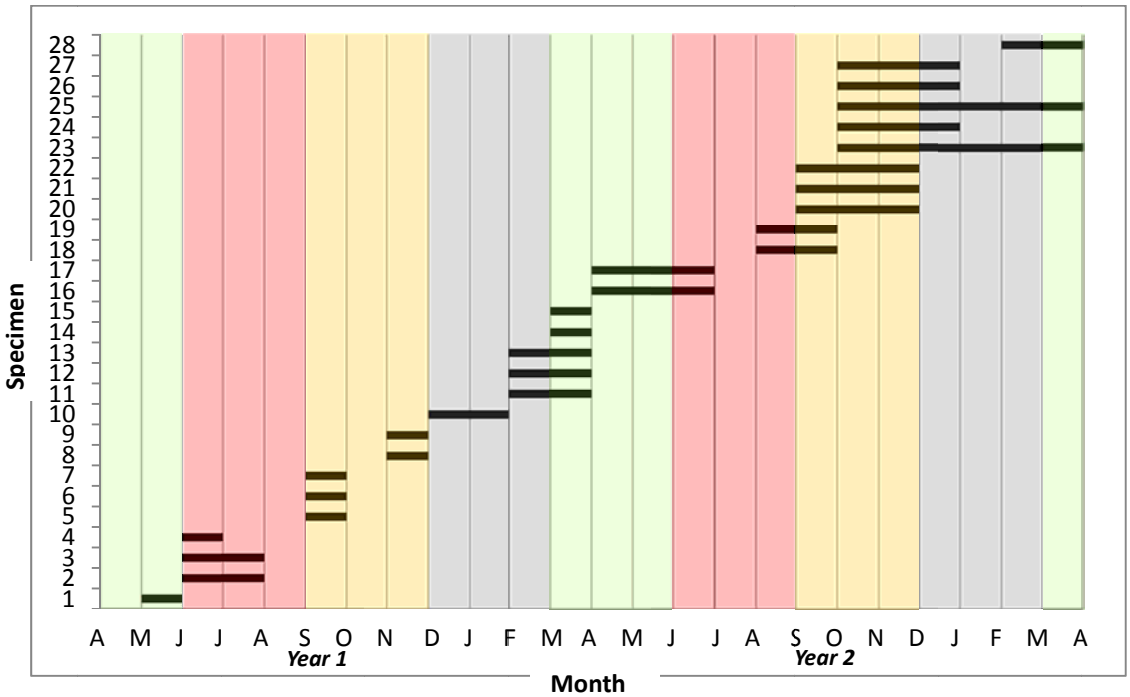


Figure 7.14 Seasonality of pig slaughter at Tianluoshan, summarized from tooth ageing of 28 specimens. Four seasons are represented by different colours: green for spring, red for summer, yellow for autumn, and grey for winter.

Wild boar hunting is an important component in the subsistence economy of Tianluoshan rather than an isolated event. On one hand, it depended on the life history and behaviour of wild boar; on the other hand, it might be related to time

and labour management in the subsistence economy. This will be discussed further in The next chapter.

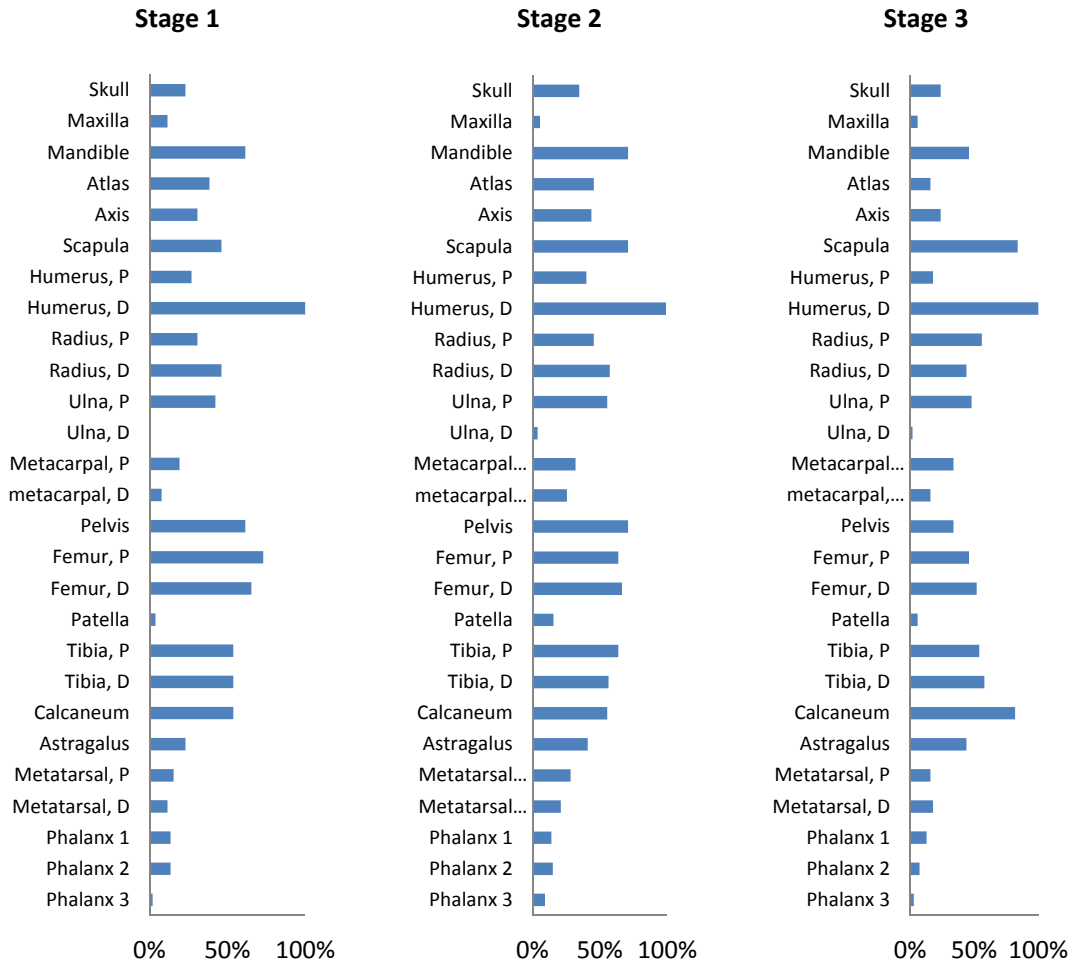


Figure 7.15 Body part representation of Sika deer from Tianluoshan, three stages separately.

7.3 Sika deer

Sika deer (*Cervus nippon*) is named after its Japanese name, where 'sika' means 'deer' in Japanese. As the widest distributed cervid in the East Asia, sika deer are commonly found at Neolithic sites across China. 2486 pieces of sika deer bones are included in this project, taking up more than a third of the total NISP. It is the most important meat resource among the five main food mammals at Tianluoshan, and the statistics suggest that its proportion increases though time (details see Table 7.1

and Figure 7.3). Despite of the rich remains that have been uncovered, the hunting activities and strategies for sika deer are barely discussed in the academic history of Chinese archaeology. Wang discusses the hunting strategy for sika deer from the Wayaogou site in Shaanxi Province, and comes to the conclusion that selective hunting was practiced during the Yangshao period (Wang, 2011, Wang et al., 2014). Japanese scholars have contributed to the methodological studies of sika deer remains based on their research on the modern specimens (Ohtaishi, 1980, Koike and Ohtaishi, 1985, Uchiyama, 1999, Koike and Ohtaishi, 1987).

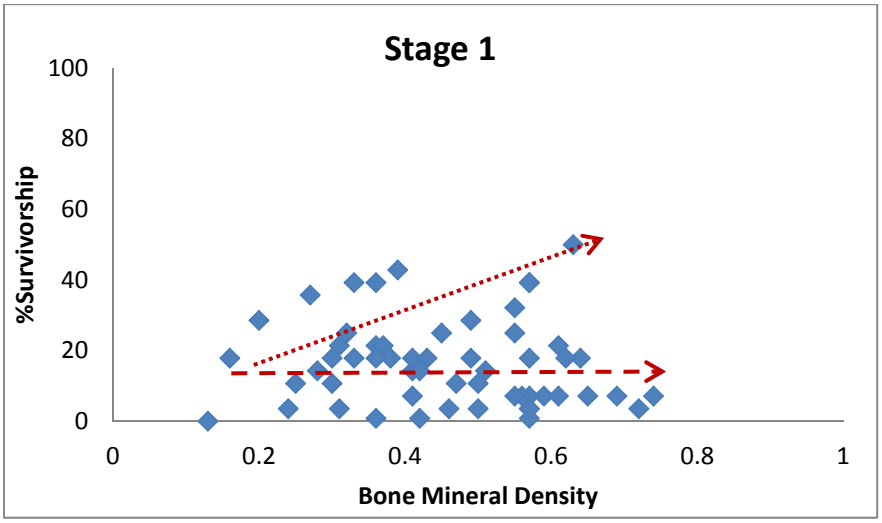
This study aims at interpreting the hunting strategy of sika deer at Tianluoshan, from the aspects of kill-off patterns and hunting seasons. Body part representation will also be presented, in order to provide information about taphonomic process which influences the discussion.

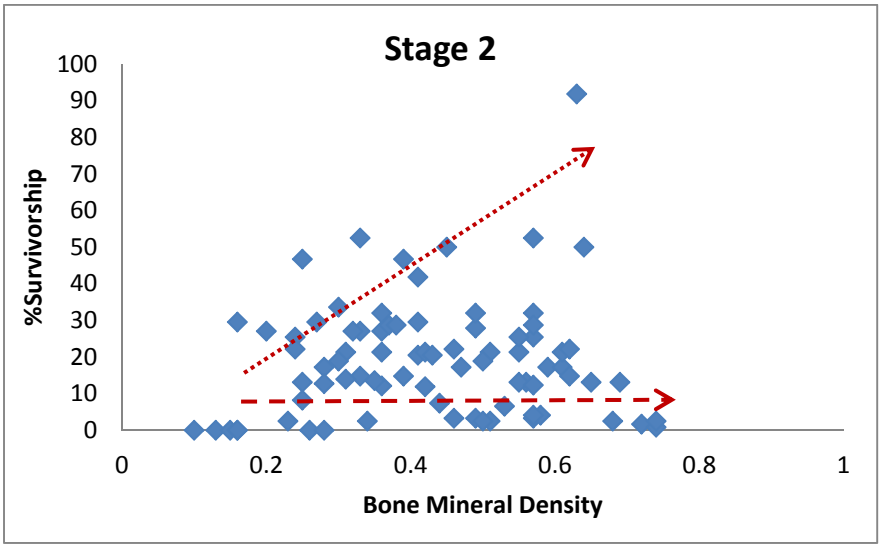
7.3.1 Body part representation

The body part representation of sika deer is displayed in Figure 7.15, arranged by stage (data see Appendix 3). According to the charts, the body part representation shows great similarity between three stages. All skeletal parts are presented at site, indicating *in situ* processing and consumption. The survivorship of skeletal parts can be affected by several factors, including bone density, transport, butchering and discard. Among all the factors, bone density, as the attribute of bones, plays an important part in the skeletal part representation. The relationship between skeletal survivorship and bone mineral density of sika deer is plotted in Figure 7.16. A comparison of the survivorship in three stages will help to evaluate how the factors influence the survivorship of sika deer bones. Since the bone mineral density of sika

deer has not been studied, the values of white-tailed deer (*Odocoileus virginianus*) from Lyman's (2004) study are used, based on the assumption that deer with similar body size may have similar bone density of the same skeletal part.

The scatterplots show a few characteristics of the relationship between bones mineral density and bone survivorship. First of all, Figure 7.16 does not show a density mediated attrition. As in the survivorship of pig bones, two trends can be detected in the distribution of scatterplots, and they are marked with the arrows. The upper arrows indicate the positive relation between bone mineral density and survivorship, and the lower arrows indicate that these two elements are less relevant. In general, they suggest that the survivorship of sika bones are influenced by conplex factors rather than a single one. Second, according to the distributions, the influence of bone mineral density increases from early to late Tianluoshan stages (the upper arrows in Figure 7.16). The influential factor acting in this part is possible the taphonomy. As was mentioned previously, specimens from the lower layers are less weathered than those from the upper layers due to waterlogging. In the same environment, bones with high mineral density are more resistant to taphonomic processes. It explains the density mediated attrition in Stage 3. Third, the bones with highest density (greater than 0.65) have very low survivorship in all three stages. By cross-referencing these values with skeletal parts, they are mostly the shafts of limb bones, including metacarpal, metatarsal, tibia, and radius. These parts are frequently fragmented for both bone marrow extraction and bone working (Figure 7.17). Once fragmented, they are usually unidentifiable.





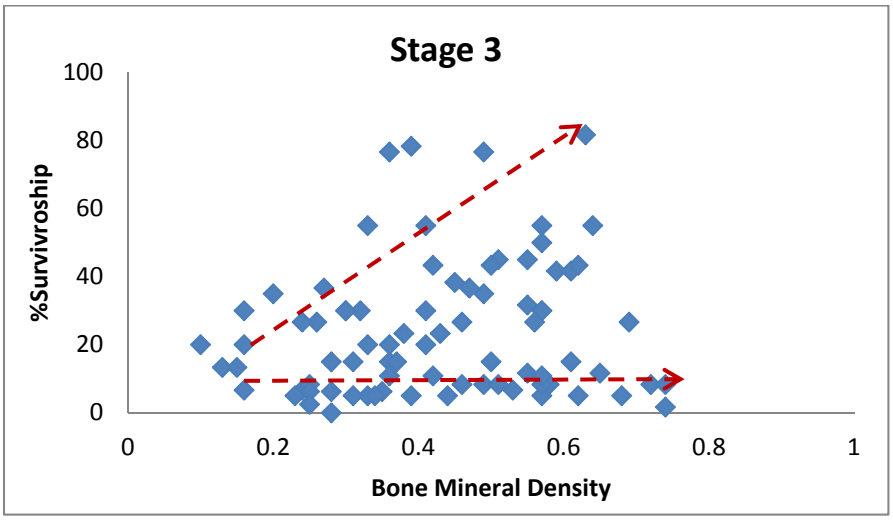


Figure 7.16 Scatterplot of % survivorship of sika deer skeleton parts from Tianluoshan against bone mineral density values. Bone mineral density references Lyman 1994.

Figure 7.17 Debris from bone working. Specimens are collected from layer 7 (Stage 1) in T103.

7.3.2 Age structure of the cull

The age of sika deer is estimated from teeth eruption and dental wear using the 'tooth wear index' by Ohtaishi and colleague (Ohtaishi, 1980, Koike and Ohtaishi, 1985). The eruption of molar teeth was used to determine the age at death of young individuals. For the adult deer which have M3 erupted, the age at death is estimated by dental wear. An index code is given to each molar during recording, and the age is decided based on the data given in Table 4.4.

A total number of 141 mandibles are used for ageing, including 30 mandibles from Stage 1, 87 from Stage 2, and 24 from Stage 3. Figure 7.18 shows the cull patterns of sika deer at three Tianluoshan stages. It appears that sika deer of all ages are targets for hunting, and the age structure does not change through time. The histograms do not show a clear pattern on the distribution of age, but the proportions of sika deer younger than 3.5 years old and older than 7.5 years old are

slightly higher than the others. How does the age structure indicate the sika deer hunting strategy? Understanding the life history of sika deer will help to interpret this cull pattern.

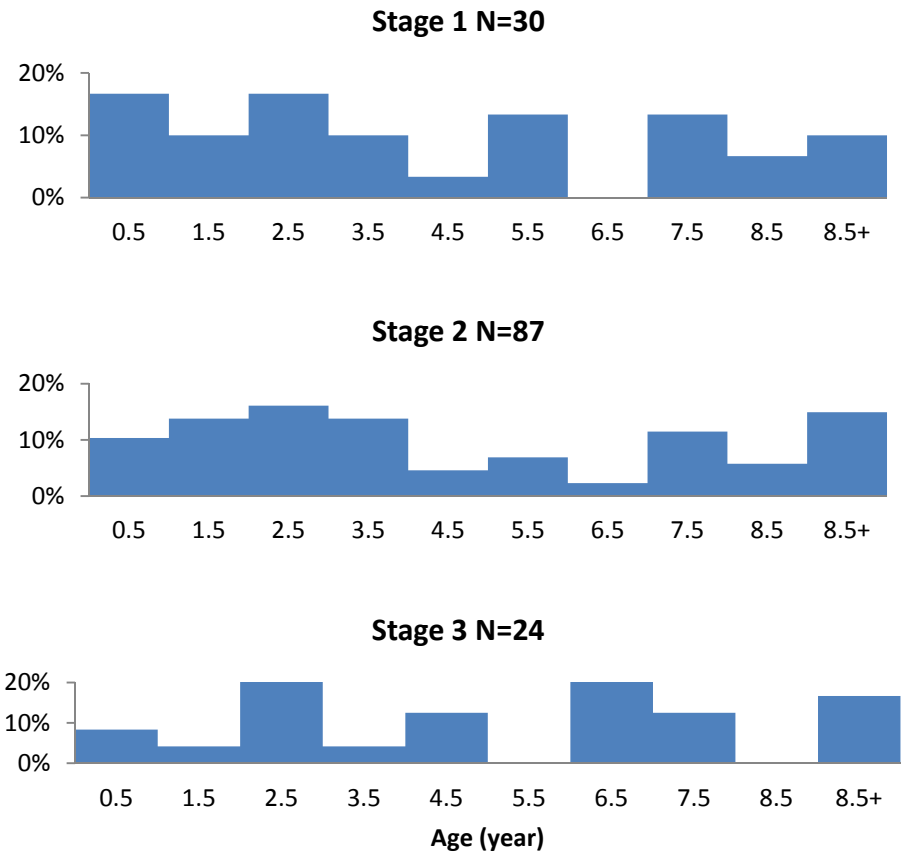


Figure 7.18 Cull patterns of sika deer at Tianluoshan, with three stages presented separately. The data for ageing are referenced from (Koike and Ohtaishi, 1985, Brown and Chapman, 1991, Brown and Chapman, 1990, Uchiyama, 1999).

The lifespan of captive sika deer is usually 15 to 18 years; the ones live in conservation (Nara Park in Japan) can live up to 26 years old, but the lifespan for wild individuals which live under predation or hunting is much shorter, approximately only half of the maximum record, and individuals over 10 years old are quite rare. The ageing method used in this study can only identify specimens younger than 9 years old, as the specimens older than this age have very heavily worn teeth and cannot be

told apart.

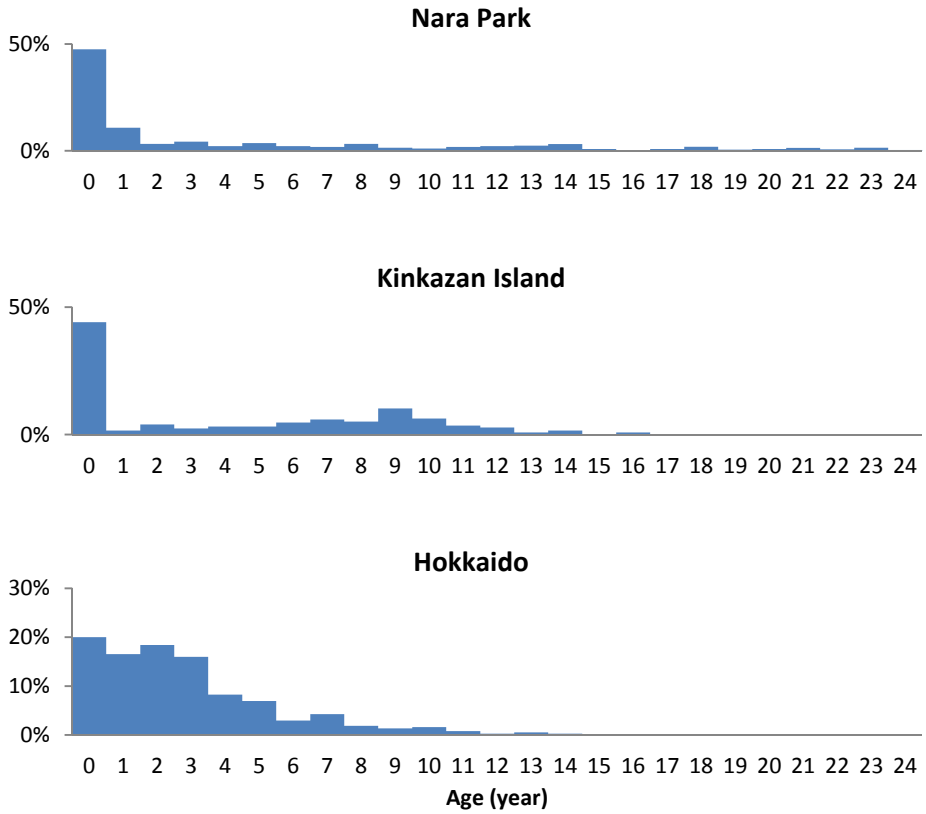


Figure 7.19 The age structure of three modern samples in Japan, based on Koike and Ohtaishi's research (1987): 1) Nara Park conservation, where sika deer are fed and protected as sacred animals, so that the age composition is regarded to represent the physiological longevity for the species; 2) Kinkazan Island, where sika deer are protected against hunting but not fed, so that the age composition may represent the ecological longevity of the species; and 3) Hokkaido, where the sika deer population is hunted, but hunting female deer is forbiddened. The histograms are generated from the original data provided in the research paper.

The life history of sika deer can be classified into five life-stages: fawn, yearling, juvenile, adult, and senescence (Miura and Tokida, 2009). Deer under 1 year old are fawns, which stay with their mothers, and have few behavioural differences between sexes. Fawns have a very high mortality rate (Figure 7.19, age '0' at Nara Park and Kinkazan Island), which is known to occur mainly within the first few weeks and during the first winter (Guinness et al., 1978, Clutton-Brock and Albon, 1982, Gaillard

et al., 1993). Yearlings are between 1 year and 2 years old, when males start to grow antlers. Yearlings have a relatively higher mortality rate than juveniles and adults. The juvenile stage is from 2 to 3 years old, and both sexes reach sexual mature. Females are able to reproduce, but males cannot get the opportunity to mate due to social hierarchy. The survivorship of juveniles is sometimes low or similar to that of adults, and is relatively insensitive to external conditions. The adult stage is generally from 3 years old to beyond. Deer in senescence usually suffer from different rates of body weight loss, probably due to the effect of tooth wear (Ohtaishi, 1975). They are vulnerable to predators and change of external conditions. Research also shows a sex-related mortality rate, where the mortality of males is usually much higher than that of females (Minami et al., 2009b). This describes the general pattern of survivorship and mortality, but the details may vary between places due to differences in environment and hunting pressures.

7.3.2.1 Interpretations to the characteristics of sika deer age structure at Tianluoshan

Figure 7.18 shows that almost half sika deer at Tianluoshan are adults, among which, about 1/3 belong to the senescence life-stage (over 8 years old). According to the body growth model of sika deer, body weight increases rapidly until three years, stabilizes until about 10 years, and gradually declines thereafter (Miura and Tokida, 2009). Therefore, hunting adults can maximize meat return. Besides, sika deer have other uses apart for being an important food resource. Their bones and antlers make quality materials for tool making. It has been introduced in chapter 2 that bone and antler tools are featured in the Hemudu material culture. Antlers are so important that the Tianluoshan people also collected shed antlers. Antlers of sika deer and

sambar are found beside the stream, in the same area as the paddles, possibly being prepared for manufacture afterwards. Even the modern hunters in Hokkaido, who no longer need antlers to make tools, tend to select adult males with antlers as game. Meanwhile, the proportion of fawns is much lower than that at Nara Park and Kinkazan Island, likely out of concern for efficiency, and the fact that fawns are are difficult to find in the forest (Koike and Ohtaishi, 1987).

In addition, the Tianluoshan sika deer also have a high proportion of juveniles and yearlings. This seems to conflict with maximizing the yield as these deer have not reached their maximum body weight. As a matter of fact, there are several ways to manage a resource to make it sustainable, which includes deliberate hunting of premature animals. Modern moose hunters in Quebec are advised to shoot one calf rather than the adult when encountering a doe with two calves, as this can increase the moose population in future years (Rowley-Conwy, 2001, Figure 3.8). For some species, a low population can stimulate the females to reproduce more offspring, and the food will be plenty for the newborn.

Another reason which leads to the juvenile-dominant cull pattern is the behaviour of deer themselves. Some prey behaviour may put the juveniles into relatively dangerous places, making them easy to hunt. In some *Cervus* species, such as roe deer and *Cervus canadensis*, juveniles are usually driven away from their mothers by the males as the rut approaches. These inexperienced young males behave erratically and become the targets for hunting (Altmann, 1960). This seasonal exile of juveniles is not observed in sika deer populations. Instead, adult males are solitary for most of the year but sometimes band together, while females and their

calves form groups of 2-3 only during the calving season (Nowak, 1991, Sheng, 1992, P209-210, Minami et al., 2009a). According to Guo and Zheng's observation on the sika deer population in Tiebu natural reserve in Sichuan, China, the mortality rate of males is much higher than that of females (Guo and Zheng, 2005). The male versus female ratio for juveniles is 0.63, less than the ratio of 1 for newborns; it further drops to only 0.35 in the adult population, indicating a remarkable reduction in males, especially during the juvenile life-stage. Overall considering the life history and behaviour of sika deer, the solitary lifestyle of male sika deer might be an important reason for the high mortality rate of young males, in both nature reserve and hunting scenarios: they are inexperienced, impulsive, and thus easily targeted by predators.

To sum up, the age structure of sika deer from Tianluoshan shows the following characteristics. Sika deer of all life-stages are targeted, but the adults, senescence, and juveniles are preferred by the hunters. After analyzing sika deer's life history, growth pattern, and behaviour, we can come to the conclusion that this hunting strategy attempted to keep the sika deer sustainable, while maximizing the meat return and obtaining raw materials for tools manufacture. Besides, sex selection is also very important for sustainable hunting, and will be discussed in the next section.

7.3.2.2 Cull pattern and hunting strategy

Koike and Ohtaishi (Koike and Ohtaishi, 1987) establish three models for age structure based on their research on the archaeological remains from 14 sites: the adult-abundant pattern, the juvenile-dominant pattern, and the fawn-abundant pattern. The models and representative sites are shown in Figure 7.20.

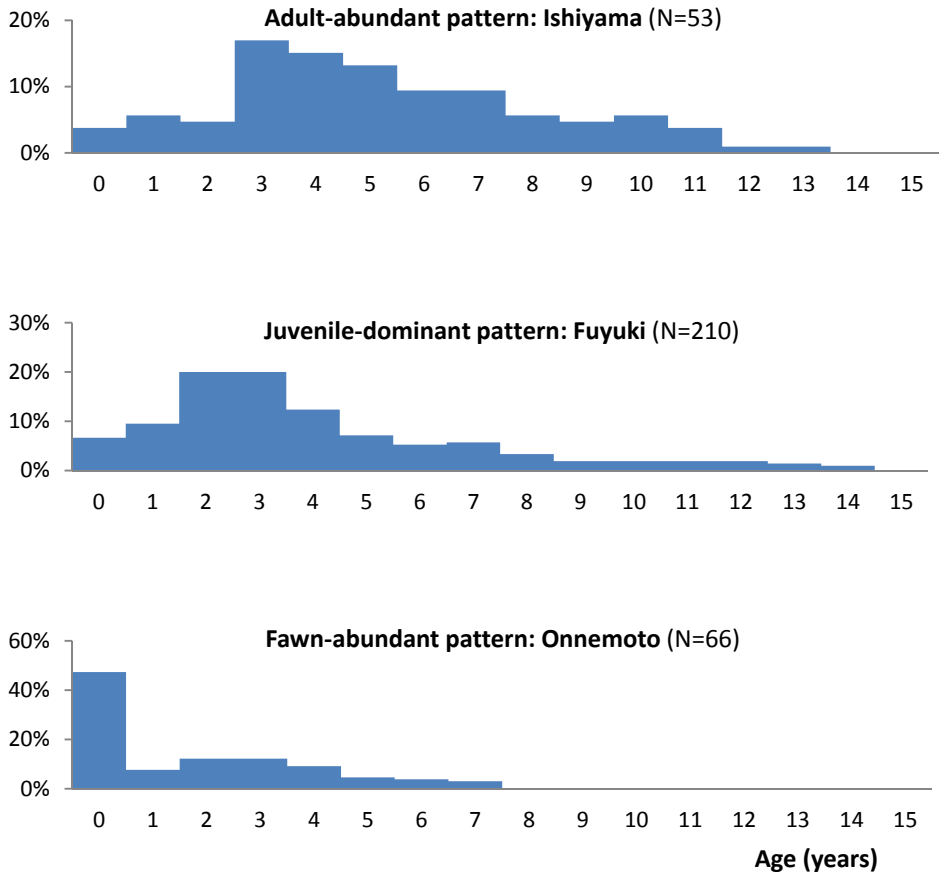


Figure 7.20 Models of sika deer age structure reconstructed from archaeological materials, reproduced from the original data given in Koike and Ohtaishi (1987). Each model is represented by a site. From top to bottom, the models are: adult-abundant pattern, represented by Ishiyama (Early Jomon), Juvenile-dominant pattern represented by Fuyuki (Late Jomon), and fawn-abundant pattern, represented by Onnemoto (1,500 – 950 BP, Okhotsk Culture).

Cull pattern can reflect the hunting techniques. A cull with age composition similar to the live population is to be expected from random-capture harvesting by intensive trapping techniques such as the drive-in traps (for the age composition of live population see Figure 7.21); and the proportion of young animals may be slightly higher as some older ones are likely to escape the traps based on their experience. By contrast, hunting techniques that targeting single animals, such as with a bow and arrow or gun, should produce stronger selection among the game animal. The indicator for distinguishing two hunting techniques is the frequency of fawns and

yearlings: a high frequency of fawns and yearlings refers to catastrophic hunting such as trapping, while a low frequency indicates individual hunting. Therefore, the three models indicate different hunting techniques that were used at the sites. Individual hunting was practiced at Jomon sites such as Ishiyama and Fuyuki, and trapping was used at Onnemoto, an Okhotsk Culture site.

Plus, the change of age structure models is synchronous with the chronological change of archaeological sites. According to the statistics, the adult-abundant pattern appears at two early Jomon sites among the 14 sites, Ishiyama and Torihama. By the late Jomon and Yayoi Period, older deer become rare, and deer younger than 5 years old become the major target. However, the fawn-abundant pattern may be an exception in that study. It only appears at the Onnemoto site in Hokkaido, and is different from other contemporary sites.

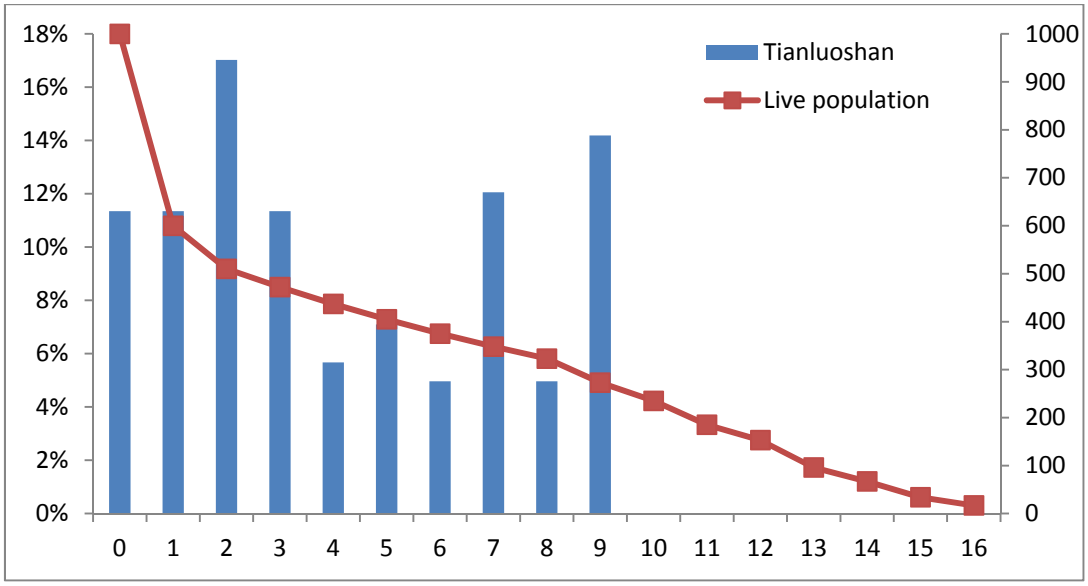


Figure 7.21 A comparison of sika deer age structure at Tianluoshan with the live population. The age structure of the live population is a simulated stationary condition using modern statistics from Japan (Koike and Ohtaishi, 1987).

The age structure of Tianluoshan is not identical to any of these models; it seems to fit between the adult-abundant pattern and the juvenile-dominant pattern. Figure 7.21 shows the comparison of Tianluoshan cull pattern against the simulated age structure of the sika deer population. Clearly the Tianluoshan age structure has a low frequency of fawns and yearlings, and both patterns are totally different, indicating individual hunting during the Hemudu period.

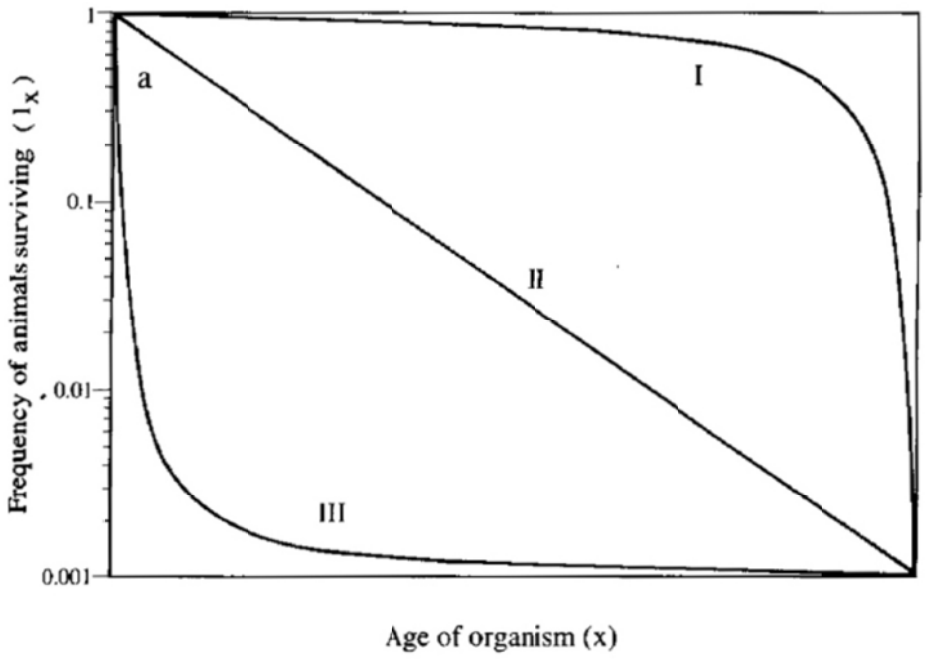


Figure 7.22 Hypothetical survivorship curves, showing the correlation model between age and population. The population is represented by a logarithmic scale. The classification of three types follows Deevey (1947).Type I organisms have high survivorship throughout life until old age sets in, and then declines steeply. Type III organisms have very low survivorship in early life. The survivorship of type II organisms regularly decline throughout life.

7.3.2.3 Survivorship and hunting pressure

In the study of modern animals, life table and survivorship curves are commonly used to examine the life history of a population. The survivorship curve is displayed by the logarithm of the frequency of surviving individuals against age. There are three theoretical survivorship curves showing different life history patterns (Figure

7.22). The type I curve indicates that the animals have a high survivorship rate until old age; it can represent many large animals. The type II is plotted as a straight line, suggesting that the probability of death remains constant throughout life. The type III curve indicates a high level of mortality at a very young age, but survivors have a good chance of reaching maturity. Most published survivorship curves belong to Type I and Type II or are intermediate between them. Marine species with pelagic eggs and larvae, such as oysters and most reef fish, fall into the Type III range.

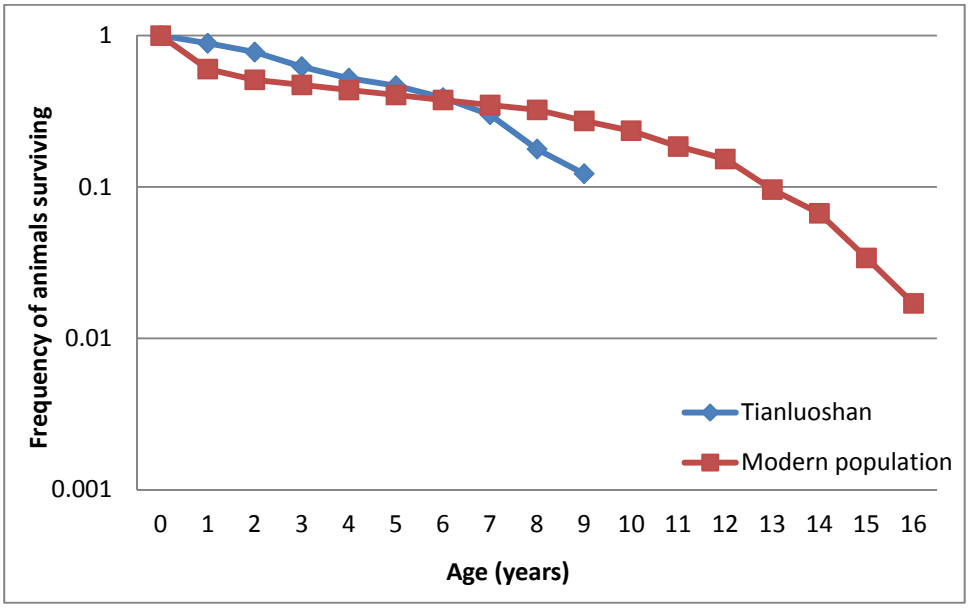


Figure 7.23 Survivorship curve for sika deer, comparing to that of modern sika deer under stationary conditions. The data of modern sika deer are reproduced from Koike and Ohtaishi (1987).

The survivorship curve of sika deer is generated from its age structure. Since the curves of three stages overlap with each other, they are added together as a large sample, and the survivorship curve is shown in Figure 7.23 alongside that of a modern population under stationary conditions as a reference sample. Compared to the theoretical patterns, clearly the survivorship curve of both modern and Tianluoshan sika deer falls between Type I and Type II, and is closer to Type I (Figure

7.22 and Figure 7.23). Survivorship curves assess the vulnerable periods in the population's life history (Reitz and Wing, 2008, P100-101). The reconstructed survivorship curve of Tianluoshan sika deer is quite close to that of the modern population, the mortality of fawns is even higher than the modern sample, suggesting that deer hunting did not threat the wild population. It is possibly related to the sustainable hunting strategies that were practiced at Tianluoshan.

7.3.3 Sex ratio

There are distinctive morphological differences between the males and females of sika deer. The does do not grow antler. Stags grow their first pair of antlers as yearlings, and start to bear full antlers at 3 - 4 years old. Sexual dimorphism also exists between two sexes: body measurements of adult males averages 8.7% greater than those of females (Feldhamer, 1980). Based on these differences between sexes, there are two ways to identify the sex of sika deer remains. First, sex can be identified from the frontlets of the skull: those bearing antlers or antler bases belong to male sika deer, and the ones without are female. Second, according to sexual dimorphism, the metric measurements on skeletal parts may show differences between sexes.

28 fragments with frontlets are recorded in this study, and 27 of them have antler bases attached. However, as most cranial bones are too fragmented to identify to species, the frontlets of female sika deer may have been overlooked, and the ones with antlers and antler bases are easier to be recognized. This result may indicate that stags are hunted more than does at Tianluoshan.

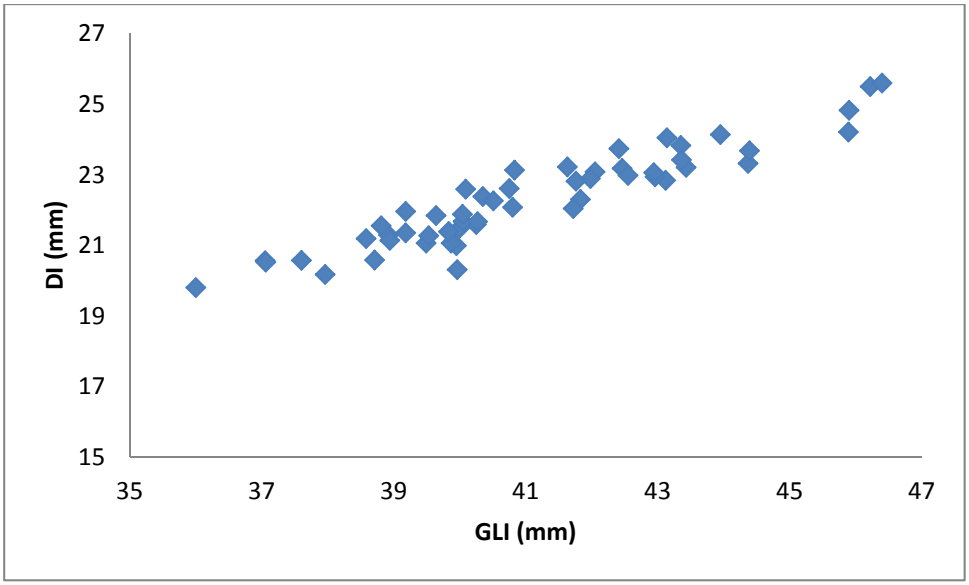


Figure 7.24 Measurements of sika deer astragalus from Tianluoshan, showing correlated data of the greatest length (GLI) and the depth (DI) of the lateral half (code following van den Driesch 1976).

The measurements of the astragalus are used to examine the sexual dimorphism of sika deer from Tianluoshan. In this case study the greatest length and depth of the lateral half of astragulas is used (Figure 7.24). The metric data show that the size range of astragulas is quite wide, indicating that both sexes were captured. However, the measurements of females and males cannot be separated. On one hand, given the 8.7% sexual dimorphism range, the measurements of both sexes can overlap. On the other hand, juvenile deer, many of which are possibly male, take a large proportion of the Tianluoshan sika deer population. According to the life history pattern described previously, the male juveniles are smaller than the adults, and are probably a similar size to the females. These factors make the size difference between sexes less distinct and more complicated.

In brief, male sika deer were possibly more intensively hunted than the females judging from the frontlets from Tianluoshan, but due to taphonomic issues this conclusion is not assured. Measurements on post-cranial bones support the

existence of both sexes at the site, but cannot separate them either. Considering the interpretations of age structure and sika deer life history, this stag-abundant hypothesis seems to fit well with other elements in the ecosystem. With more data gathered in the next step, this question will be more clearly solved.

7.3.4 Seasonality: the hunting seasons for sika deer

Sika deer have regular life cycles. The breeding and birth time may vary due to the change of climate and environment (Sheng, 1992). According to the research on the modern sika deer population in the lower Yangtze River region, breeding occurs from September to December, and the birth of a single calf occurs around mid-May (Yu, 2008). Antler shedding occurs in April and May, and thereafter stags grow a new pair during summer to get ready for the rutting season in autumn.

The sika deer hunting seasons can be narrowed down by observing the antler growth and shedding pattern of the male skulls. 26 out of the total 27 male frontlets have antlers attached, indicating that these were killed between summer and spring of the next year. Only one was killed after antler shedding.

Since antler shedding time can only slightly narrow the hunting seasons, dental ageing may help to further define an exact time. Cull months are estimated using mandibles of fawns and yearlings the age of which is determined using teeth eruption. The teeth eruption and replacement sequence is shown in Table 7.5. As the age is shown in 6-month classes, the wear pattern of the M_1 and M_2 is also considered to make the age identification more accurate. The results are shown in Figure 7.25.

Table 7.5 Tooth eruption and replacement sequence of sika deer, based on Koike and Ohtaishi's research on the modern population (Koike and Ohtaishi, 1985, Table 1).

Winter	**Age (months)**	**Teeth eruption**
1st	0	$i_1\ i_2\ i_3\ c\ m_1\ m_2\ m_3$
	6	$i_1\ i_2\ i_3\ c\ m_1\ m_2\ m_3\ M_1$
	12	$i_1\ i_2\ i_3\ c\ m_1\ m_2\ m_3\ M_1\ M_2$
2nd	18	$I_1\ I_2\ i_3\ c\ m_1\ m_2\ m_3\ M_1\ M_2$
	24	$I_1\ I_2\ I_3\ C\ m_1\ m_2\ m_3\ M_1\ M_2\ M_3$
3rd	30	$I_1\ I_2\ I_3\ C\ P_2\ P_3\ P_4\ M_1\ M_2\ M_3$

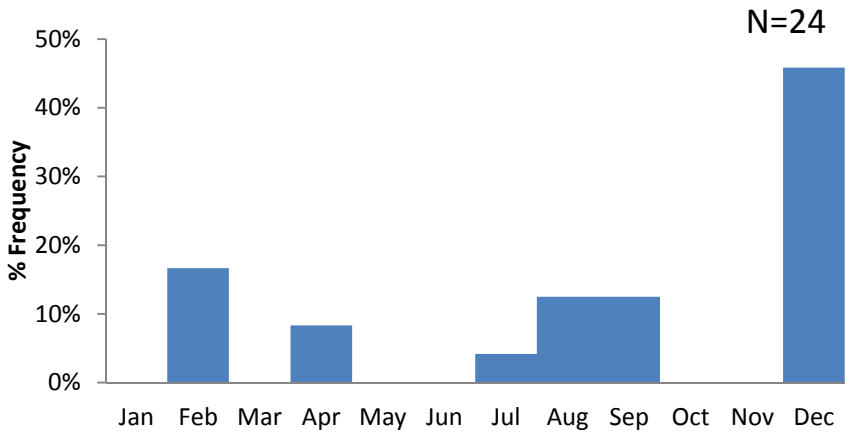


Figure 7.25 Hunting seasons estimated from dental ageing of fawns and yearlings of sika deer from Tianluoshan.

It appears that nearly half of the sika deer, regardless of sex, are killed in December, or at least during winter time. This conclusion tallies with the result derived from antler shedding. It is possible that those killed in winter are mainly males, as killing females during gestation period harms the sustainability of the entire deer population. However, winter hunting is not quite economic from the perspective of maximizing the yield of hunting, because males have deleted their fat stores and may have lost up to 20-30 percent of their body weight (Feldhamer, 1980); but could help to overcome the food shortage in winter.

7.4 Muntjac

Muntjac is the second most hunted animal, by NISP and MNI, in the Tianluoshan fauna. It is an adaptive small deer in the temperate zone China. However mostly restricted by retrieval strategies, muntjacs have been barely studied. As an adaptive and fast breeding animal (details about habitats will be presented in the next chapter), they can be a stable food resource for the Neolithic settlements. In this study, muntjacs are analysed for the interpretation of the Tianluoshan hunting strategies, based on the discussion of body part representation and the reconstruction of cull patterns.

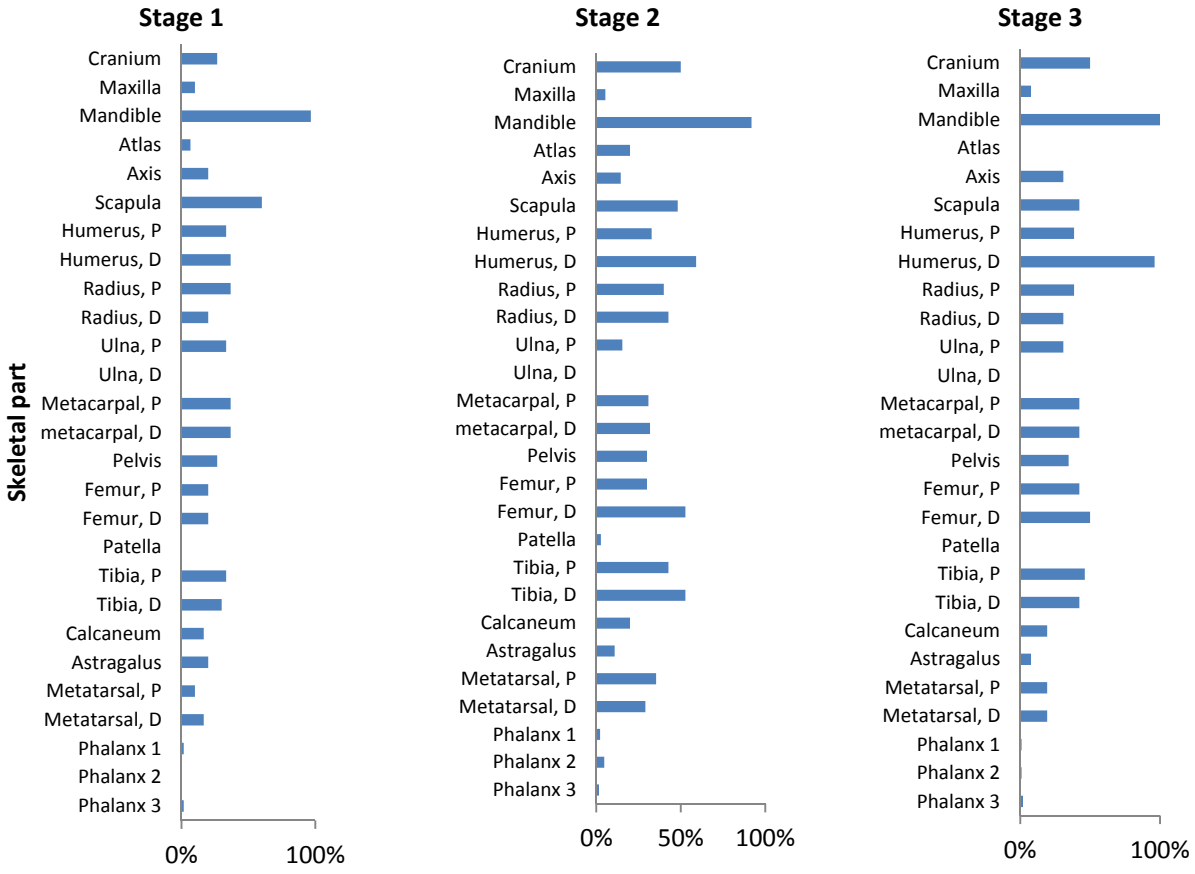
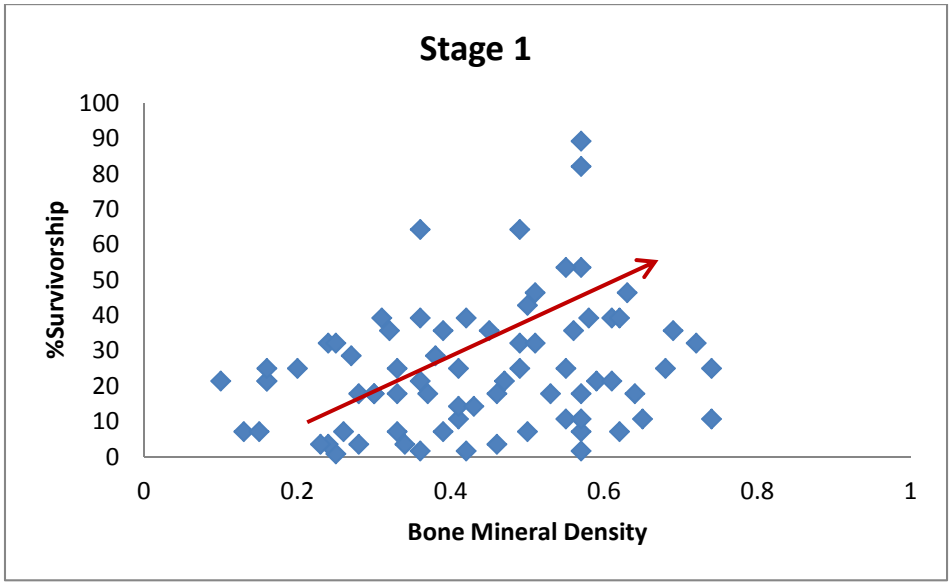
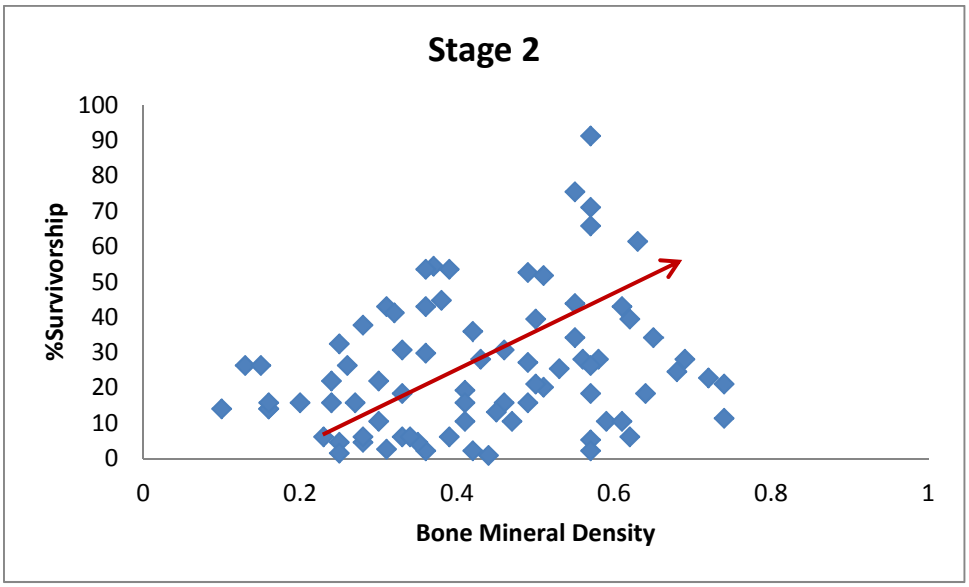


Figure 7.26 Body part representation of muntjacs from Tianluoshan (Appendix 5).





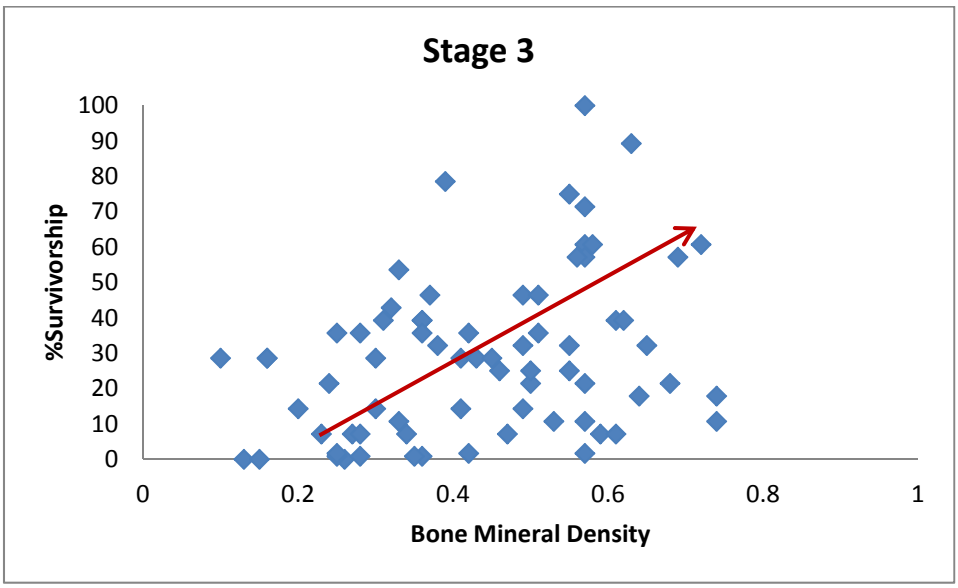


Figure 7.27 Scatterplot of % survivorship of muntjac skeleton parts from Tianluoshan.

7.4.1 Body part representation

The body part representation shows an even distribution of all skeletal parts, but small bones, such as patella and phalanx, are barely collected, apparently due to retrieval methods. Since muntjac bones are too small for tool making, many long bones are found complete with both ends, as seen in Figure 7.26. The overall presentation at site also indicates an *in situ* processing and consumption.

The survivorship of the muntjac bones is plotted against bone mineral density in Figure 7.27. Since the bone mineral density of sika deer has not been studied, the values of white-tailed deer (Odocoileus virginianus) bone density from Lyman's (2004) study are used for analysis. It may lead to some error because of the size difference, but similarities can be expected between species within the same family.

A density mediated survivorship can be observed in all three stages from Tianluoshan. It suggests that the survivorship of muntjac bones is mostly influence by taphonomy, so that denser bones have more possibility of being preserved. Non-taphonomic influences such as bone working are minor, because muntjac bones are not ideal materials for making tools.

7.4.2 Ageing

The age at death of muntjac is estimated using the method developed by Chapman and colleagues (1985, 2005). As seen in Figure 7.28, the sample size in each stage is small. The number of mandibles which qualify for age determination is much smaller than the expected number, because many mandibles do not contain all three molars. When a molar is absent, the wear pattern and score (for method see Chapter 4) can only be estimated from the other two. Under this situation, the most

frequently appeared combination according to Chapman and colleagues' work is chosen; therefore, the total score may be clustered, especially for the older individuals as shown in Figure 7.28.

The age structures indicate that the individuals of different age in the muntjac population were targeted during hunting. The youngest and the oldest individuals were more frequently captured. The cull pattern of modern samples is used to evaluate the hunting activities at Tianluoshan.

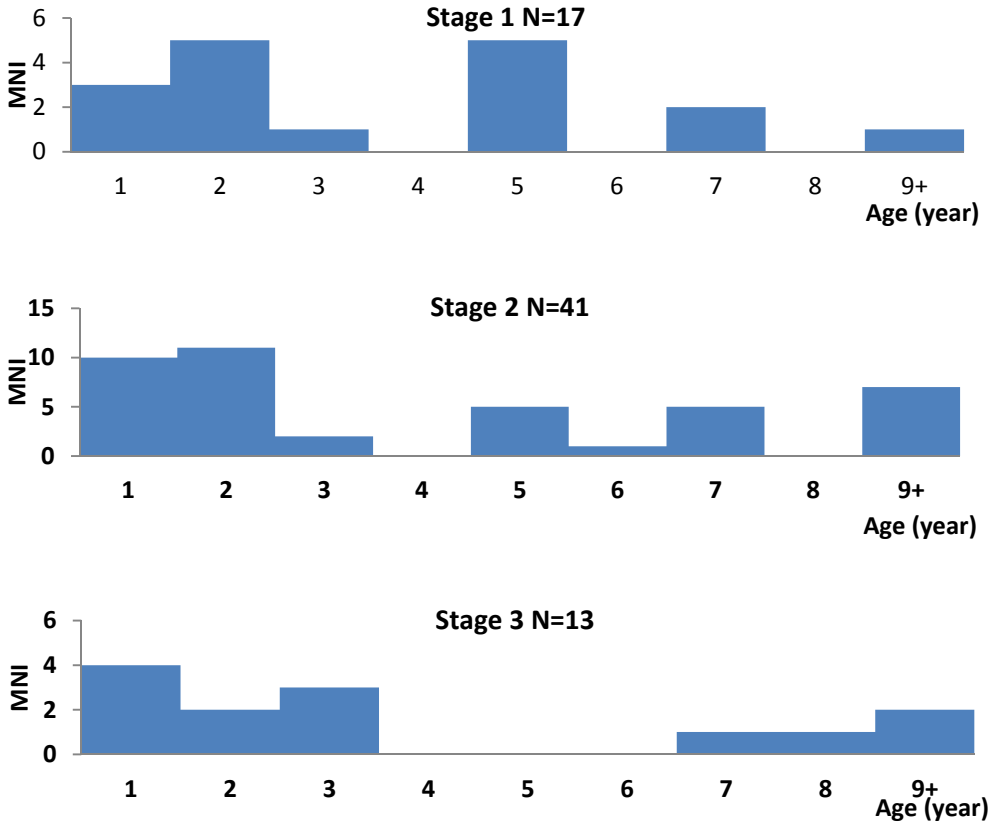


Figure 7.28 Cull patterns of muntjacs at Tianluoshan, with three stages presented separately.

Muntjacs in the wild environment can live for up to 9 years. A survey research practiced in the 1980s revealed the age composition of the wild population under severe hunting pressure. According to the research, the population mainly consisted

of juveniles and young adults under 3 years old (87.8%); adults older than 4 only took 12.2% of the entire population (Sheng et al., 1990). The cull pattern is shown in Figure 7.29. Young muntjacs have a high mortality rate, and few individuals can live to old age. The high hunting pressure is responsible for this cull pattern. As shown in Figure 7.30, the survivorship curve of the modern population accords with type II of the theoretical model (also see Figure 7.22). On the contrary, many muntjacs at Tianluoshan are killed at old age (e.g. ≥7 years old), indicating a relatively high survivorship rate. The survivorship curve of Tianluoshan muntjacs is close to Type I, showing a significant difference from the overhunted modern population. Therefore, both the cull pattern and survivorship curve indicate that the hunting pressure on Tianluoshan muntjacs was within the capacity of their population.

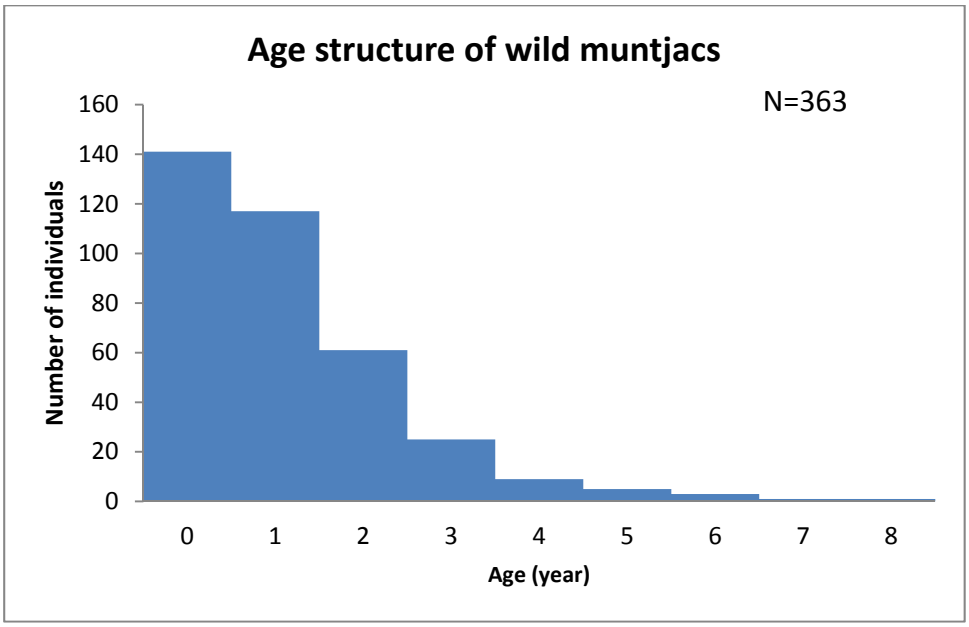


Figure 7.29 Age structure of *Muntiacus reevesi* population in the 1984/1985 hunting season in Southeast China. Reproduced from data in Sheng and Xu (1990).

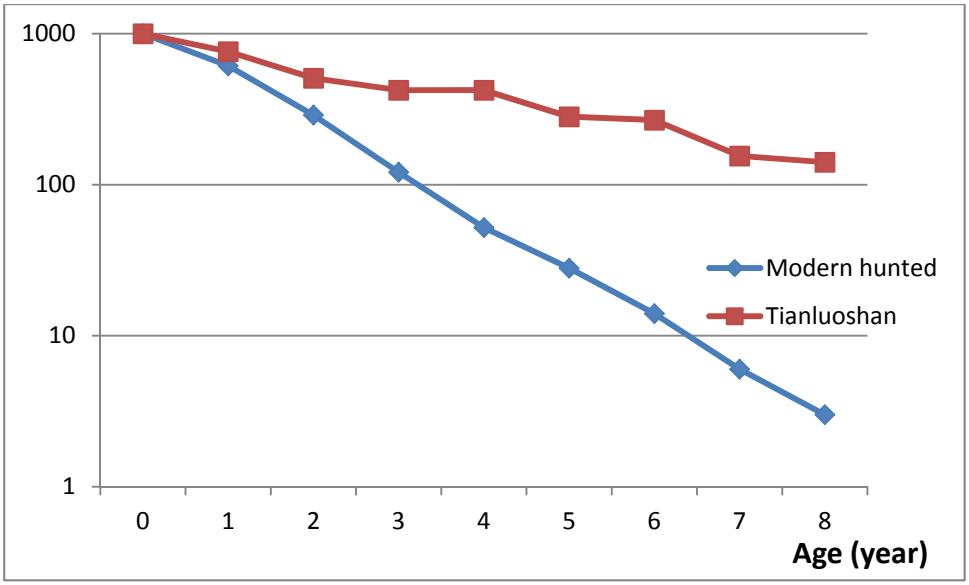


Figure 7.30 Survivorship curve of muntjacs, summarized from the cull patterns.

Muntjacs can breed at all months throughout the year. According to field survey, the number of neonates is almost evenly distributed in each month (Sheng, 1992, Table 6.26). Therefore, it is impossible to find out hunting seasons from dental ageing. The hunting seasons can be narrowed down slightly using antler replacement. Interestingly, although male muntjacs grow their antlers at different times of year (when 4-6 months old), casting of the antlers occurs in May and June, replaced by a new pair soon afterwards, and cleaning of antlers occurs from mid-August to mid-October, irrespective of the munjac's date of birth (Chapmand and Chapman, 1982). The male muntjac frontlets retrieved at Tianluoshan all bear antlers, suggesting that they were killed at any time of year but summer.

7.5 Discussion

This chapter presents the overall composition of the Tianluoshan animal assemblage, and gives an interpretation of the major food animals. The range and relative importance of animal species indicates a wide range of species in the

assemblage, and only a few of them are extensively exploited. From more to less by NISP, the major food mammals include sika deer, muntjac, pig, sambar, and water buffalo. Three of them are analysed individually in this chapter, in order to investigate the subsistence at Tianluoshan during the Hemudu Period.

7.5.1 Subsistence economy of Hemudu Culture judging from animal remains

In general, the subsistence economy at Tianluoshan relies on the wild resources especially the ungulates.

This chapter attempts to investigate the attributes of pig remains from Tianluoshan, and further to interpret the development of pig exploitation in the Neolithic, given the importance of this topic in Chinese archaeology. The analysis of morphometric data and cull patterns indicates that the Tianluoshan pig assemblage probably represents the remains of wild boars. The comparison of Tianluoshan with other sites suggests that pig domestication in the lower Yangtze River region might have appeared later than previously proposed.

Meanwhile, cervids make up the predominant part of the animal assemblage at Tianluoshan. Sika deer and muntjac are the most extensively exploited species judging by NISP and MNI. The analysis of age structure, sex ratios, and seasonality of the deer reveals a well-organized and sustainable hunting strategy. There could have been a definite selection on age, sex, and season when hunting was practiced.

7.5.1.1 Age selection

Pig, sika deer, and muntjac all show specific age structures, and each keeps its pattern steadily throughout the three stages of Tianluoshan occupation, indicating a

customized hunting plan for different species. For pigs, juveniles and young adults are the favoured targets. For sika deer, the senescence is another preferred target as well as juveniles and young adults. The muntjacs show the same patterning.

There are common points between those hunting strategies. Juveniles and young adults have always been the major target no matter what the prey is. Previously, the abundance of young individuals, even though in some cases they are just young adults, has been used as important evidence for pig domestication in the lower Yangtze River region. Yet, as is discussed by Rowley-Conwy et al. (2012), the age structure can be influenced by many factors, natural, attritional, or intentional. Under these circumstances, knowing the age structure and survivorship of the wild population can help to interpret the questions.

The cull patterns indicate that two goals were achieved at Tianluoshan: maximizing the yield from hunting whilst keeping the resource sustainable. The age structures do not show significant change through time during the occupation of Tianluoshan, indicating that the resources were well managed rather than over-exploited.

7.5.1.2 Scheduling

Tianluoshan is a settlement site which is occupied all year long. The kill season reconstruction of pigs and deer show that hunting takes place in all seasons of the year, but are concentrated in certain months. A difference between species can be observed from the results. According to the reconstruction, the busy pig hunting season is possibly in summer; conversely, sika deer are mostly killed in winter. The growth and behaviour of muntjac do not show seasonal change, but the replacement

of antlers always occurs at the same time of year. The hunting season of muntjacs can be thus narrowed down to the nine months when males bear antlers.

The varied hunting seasons targeting different animals probably imply a well-designed hunting timetable. Together with the fishing seasons discussed in Chapter 6, this will contribute to the reconstruction of scheduling in the entire subsistence economy, and will be further discussed in the next chapter.

7.5.2 Species spectrum change in the Lower Yangtze River region

The relative proportions of taxa do not show much difference within Tianluoshan, possibly due to the short time span and consistent single-cultured occupation. What was the development of subsistence economy like? The answer starts by putting Tianluoshan in the chronological sequence of the lower Yangtze River region,

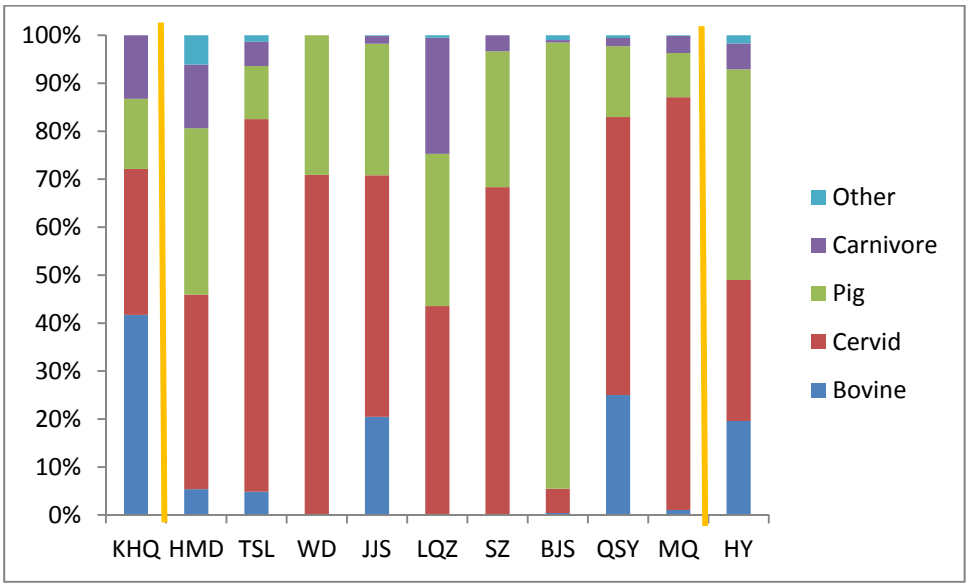


Figure 7.31 Relative proportions of the mammal categories at sites in China. Chronology of the sites is listed in the caption of Figure 7.8.

In order to answer this question, ten sites ranging from early Neolithic to Bronze Age with animal remains studied and reported are selected for comparison. The animals from each assemblage are categorized into four groups: bovine, cervid, pig,

and carnivore. The rest are all grouped in the 'other' category. The composition of each mammalian faunal is reproduced, and the results are plotted in Figure 7.31.

Figure 7.32 Distribution of Neolithic and Bronze-age sites in the lower Yangtze River region. Detailed information is listed in Table 7.6.

The sites in Figure 7.31 are arranged in chronological order, indicating that the faunal composition hardy changes from the middle Neolithic Age until late Neolithic Age. The first significant change happens in the middle Neolithic age, represented by the sudden drop in water buffalo proportions. Cervids tend to be a stable food resource throughout time. Pig was the second most important resource during the Neolithic age, but became the primary resource in the Bronze Age. The increase in pig remains tend to be simultaneous with the size reduction of the lower M_3 (see Figure 7.7).

Table 7.6 Date, locations and environment at the archaeological site in China.

Site	Date	Geographic region	Environment
Jiahu	7,000 – 5,000 BC	Central Plain (Upper Huai River)	Forest, Shrub-forest, Grassland
Kuahuqiao	6,200 – 5,000 BC	Lower Yangtze River	Forest, Shrub-forest, Grassland, Wetland
Hemudu	5,000 – 4,000 BC	Lower Yangtze River	Forest, Shrub-forest, Grassland, Wetland
Tianluoshan	5,000 – 4,000 BC	Lower Yangtze River	Forest, Shrub-forest, Grassland, Wetland
Weidun	Approx. 4,000 BC	Lower Yangtze River	Shrub-forest, Grassland, Wetland
Jiangjiashan	3,900 – 3,700 BC	Lower Yangtze River	Shrub-forest, Grassland, Wetland
Longqiuzhuang	4,600 – 3,000 BC	Huai River	Forest, Shrub-forest, Grassland, Wetland
Songze	4,000 – 3,000 BC	Lower Yangtze River	Shrub-forest, Grassland, Wetland
Bianjiashan	2,800 – 2,300 BC	Lower Yangtze River	Forest, Shrub-forest, Grassland, Wetland
Qianshanyang	2,400 – 2,000 BC	Lower Yangtze River	Shrub-forest, Grassland, Wetland
Maqiao	1,900 – 1,200 BC	Lower Yangtze River	Shrub-forest, Wetland
Heying	Approx. 1,000 BC	Huai River	

To sum up, the mammalian remains from Tianluoshan indicate a hunting subsistence economy which relies on the wild ungulates in the Hemudu Period. A well-designed and sustainable hunting strategy is revealed from the analysis. These data shall be integrated with those from the fish remains study and archaeobotanical study, to interpret the full subsistence economy entirely.

Chapter 8 Animal procurement and subsistence economy at Tianluoshan

This chapter summarized the subsistence economy of Tianluoshan from the analysis of animal remains, including an overall presentation of the food resources, the temporal dimensions and spatial dimensions of resource exploitation, hunting/fishing strategies and techniques, the discard patterns within the site, and a broad view of the subsistence economy in the lower Yangtze over the Neolithic. The interpretation focuses on the animal subsistence, but the archaeobotanical results are integrated, in order to interpret the subsistence as an ecosystem rather than segmented.

There are generally three parts to this chapter. Part one reconstructs the palaeo-environment based on the habitats of animals in the assemblage. An ecological index, 'Taxonomic Habitat Index (THI)', is introduced to allocate each species into several values based on their habitat preference. The palaeo-environment reconstruction also forms the basis for discussing the spatial dimensions of resource exploitation in the next section. Part two summarizes the subsistence economy by animal species, and then presents the scheduling and range of the resource exploitation at Tianluoshan, with animal and plant datasets integrated. The hunting and fishing strategies, skills, and techniques are further discussion in this section. The analysis of the bone distribution aims to reveal the intra-site difference which may be related to the functional variation within Tianluoshan. Part three attempts to view the subsistence economy in a broader background of the lower Yangtze River region,

and discuss the chronological change over the Neolithic. Animal domestication and the unique rice-fish subsistence system are emphasized. A brief review of the subsistence in the Yellow River region is used for comparison, featuring their differences.

8.1 Ecological analysis

Ecology is about the natural environment and the interrelationships between organisms and their surroundings. It includes information about an animal's living, such as where it lives, what it eats, what, where and how it pursues food, the breeding season, living style (group or isolated), etc. Such knowledge is the fundamental of any hunting and fishing activities; hence it is accumulated and passed down by the hunters and fishermen from generation to generation. It is also fundamental for zooarchaeological studies investigating past subsistence economies. A stable subsistence system is founded on firmer ground, based on biological and ecological knowledge, allowing for repeated and reliable success in securing targeted species (Reitz and Wing, 2008, P88).

This chapter attempts to reconstruct the palaeo-ecology using the mammals in the Tianluoshan fauna, and thus to interpret the hunting activities on the basis of ecological conditions.

8.1.1 The distribution of feeding habitats

The knowledge of the life history and niche of a prey animal is critical for a successful predator. The primary among this knowledge is where and when an animal can be found. Habitat preferences and the distribution of animal populations are fundamental concepts in ecology, and understanding them is important for

interpreting human subsistence economy (Reitz and Wing, 2008, P89).

The ecological habitat preferences of the species in the Tianluoshan fauna are gathered from literature (e.g. Sheng, 1992, Sheng et al., 1998) and the Animal Diversity Web database of the University of Michigan. Since the Tianluoshan fauna also contains a few extinct species (details see Chapter 7), the habitat conditions of these animals are deduced from the existed modern species which are taxonomically related to them. The habitat of each species is summarized as follows.

There are three large mammals in the Tianluoshan faunal assemblage, including water buffalo (*Bubalus mephistopheles*), sambar (*Cervus unicolor*) and Milu deer (*Elaphurus davidianus*). The Mephistopheles water buffalo is an indigenous water buffalo in Holocene China, featuring short and strong horn cores. Archaeological evidence indicates that it belongs to the swamp buffalo type, which has an extreme preference for water (Liu and Chen, 2012, P109, Xue and Li, 2000). Research on its modern relative, *Bubalus bubalis*, suggests that *B. mephistopheles* might also inhabit forests and grasslands adjacent to water bodies. *Cervus unicolor* is a large deer native to the South/Southeast Asia and the southern part of East Asia (Nowak, 1991). They inhabit forested hillsides with a wide range of elevation, from lowland wetlands to high altitudes of 3700 m, preferring habitats close to water (Sheng, 1992). Milu deer, also known as Pere David's deer, were large deer native deer to Eastern China, represented by abundant fossil records and historical literatures. The truly wild population has disappeared from their original habitat; all modern Milu deer are offspring of 18 individuals which were transported to Woburn Abbey in England in 1898. This bottle-neck incident leads to a result that there is physical difference

between the modern and archaeological specimens. For instance, the modern antlers have simple branch structure and a relatively smooth surface, while archaeological specimens have more complicated structure with many knobs on the surface (Figure 8.1).

Two prey animals can be classified into medium sized animals, which are sika deer (*Cervus nippon*) and wild boar (*Sus scrofa*). Sika deer are adaptive deer in East Asia, although currently their habitat area in China have shrank to a few isolated forests in Jilin, Sichuan and Zhejiang (Sheng, 1992, P204, Nowak, 1991, Sheng et al., 1998, P188). Sika deer are primarily forest-dwelling, preferring forested areas with a dense understory; but the subspecies in the lower Yangtze River (Zhejiang), *Cervus nippon pseudaxis*, inhabits in the hilly areas (elevation 300-600 m) covered with tall grasses and shrubs, rarely entre forested areas (Sheng, 1992). Seasonal immigration may happen between the habitat locations. Wild boar is also an adaptive species, which can be found in the broad area of Eurasia, North Africa, and adjacent islands. They inhabit in various habitats, and prefer shrublands, moist forests and grasslands, where they can feed on fruits, tubers, roots, invertebrates and small vertebrates.

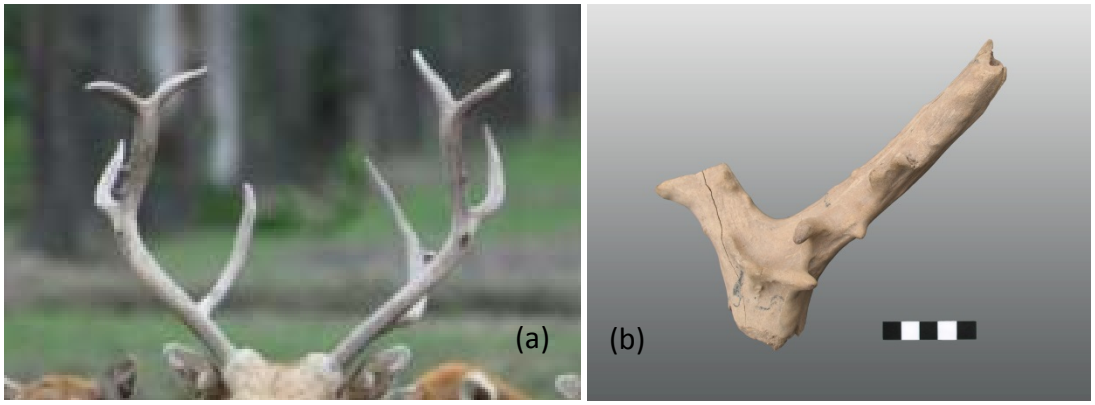


Figure 8.1 Modern Milu deer antler (a) and an archaeological specimen from Tianluoshan (b). The surface of the modern specimens is smooth without many knobs.

Among the small prey animals, muntjac (*Muntiacus reevesi*) plays an important part. It is one of the smallest deer, adult individuals weighing only 10-15 kg (Chinese muntjacs, Sheng, 1992, P126). They are native to the subtropical China and Taiwan, and were introduced to England and elsewhere since around 1900. Muntjacs inhabit subtropical scrub forests at low to moderate elevations, which are commonly distributed in the lower Yangtze River region. The Chinese water deer, a small deer of similar size to muntjac, are also present in the Tianluoshan faunal assemblage. As indicated by its common name, water deer prefer habitat close to water bodies, normally among tall reeds, rushes and grasses along rivers, or in the low hills nearby. The ratio of these two small deer can be seen as an environmental indicator. Observation on both species noticed that when the shrubs were cut down and the grasslands expanded, muntjacs disappeared quickly and replaced with water deer; when the artificial woods grew, the number of muntjacs increased again (Sheng, 1992, P129).

Apart from the ungulates, a variety of carnivores have been discovered at site, including eight species from five families (Table 7.1), which are all wild animals except for dog. Literature review of these carnivores indicates that they mostly inhabit forest and grassland areas, and some of them tend to choose habitat close to water sources, such as raccoon dog, masked palm civet and otter.;.

To sum up, the Tianluoshan fauna consists of mammals from various habitats. Some of them are adaptive to diverse and widespread habitats, such as sika deer and wild boar; the occupation of a habitat may change or expand during the daily, annual, or life cycle of these animals. These animals are less indicative of the

environment. Meanwhile, the habitat preference of a few species is specific, such as muntjac, water deer, and otter, indicating the existence of certain environment around Tianluoshan. For the convenience of next step's analysis, the habitats of the animals in the Tianluoshan fauna are further summarized in Table 8.1 and Table 8.2.

8.1.2 The ecological diversity of mammalian resources

Analysis of archaeological faunal assemblages provides clues about former environments, based on the assumption that the ecological requirements of modern taxa have not changed in the Holocene, and people concentrated their subsistence efforts within a nearby catchment area (Reitz and Wing, 2008). The environment can be inferred by the presence and absence of a species since each of them has its specific habitat range, and the indication of the environment varies between species accordingly. The animals with narrow habitats are better indicators to the environment, generally for example, insects, spiders, mites, parasites, etc.; in the case of Tianluoshan, muntjac is indicative to shrub forests. On the contrary, species which occupy a wide range of habitats are non-diagnostic, such as sika deer in the Tianluoshan assemblage. The description of the distribution and feeding habitats indicates that the Tianluoshan fauna mostly consists of animals adaptive to a variety of environments, including coniferous forest, broadleaved deciduous forest, shrubs, thatched grassland, wetlands, and possibly seashore.

The presence and absence of species helps to provide a general view of the environment, but without detailed interpretation. Therefore, the Taxonomic Habitat Index (THI) developed by Andrews and Evans is employed to discuss the paleoecology. The interpretation is made based on the habitat of species, regardless

Table 8.1 Biological and ecological information about the mammalian species in the Tianluoshan fauna.

Species	**Body size**	**habitat**	**behaviour**	**Season of birth**	**Antler shedding**
Water buffalo	Large	Grassland, wetland, riverine.			
Sambar	Large	Forest, shrub forest, grassland, wetland	Herbivore, nocturnal	Apr - May	
Milu deer	Large	Shrub forest, grassland, wetland	Herbivore	Apr - May	
Sika deer	Medium	Forest (commonly); shrubforest, grassland (subsp. in lower Yangtze)	Herbivore; nocturnal	May - July	
Wild boar	Medium	Forest, shrubforest, grassland	Omnivore; group animals	Spring	
Muntjac	Small	shrubforest	Herbivore, solitary and territorial deer	Year round	May - Jun
Water deer	small	Shrubforest, wetland	Herbivore	May - Jun	No antlers grown.

Table 8.2 Biological and ecological information about the minority mammalian species in the Tianluoshan fauna.

Species	**Body size**	**habitat**	**behaviour**
Raccoon dog	Small	Less dense forest close to water, wide adaptive	Omnivore, nocturnal
Badger ***Arctonyx collaris***	small	Forest, shrub forest, grassland	Omnivore, nocturnal
Otter ***Lutra lutra***	Small	Wetland, seashore	Ichthyophagous, solitary animal
Masked palm civet	Small	Forest and shrub forest near water	Omnivore, nocturnal
Leopard cat	Small	Forest, shrub forest, grassland	Carnivore
Marten ***Martes flavigula***	Small	Forest, shrub forest, grassland, wetland	Diurnal
Rhesus macaque ***Macaca mulatta***	Small	Forest, shrub forest, grassland	
Black bear	Large	Forest, shrub forest	Omnivore
Porcupine	Small	Forest, shrub forest, grassland	

of their relative abundance, as it can be influenced by many factors, such as the life history of the species, the capacity of an environment type, and the position in the food net.

The taxonomic habitat index is a cumulative index obtained by combining the habitat indications of all the species contained in a fauna (Andrews, 1990, Evans et al., 1981). It evaluates palaeoenvironments and palaeoecology. The habitat of each species is given a maximum score of '1'. When the animal inhabits more than one habitat type, the score '1' is broken down according to the habitat preference of that species; the preferred habitat earns a higher score. For the existing species, the scores are assessed from the ecological information, representing the possibilities that the species lives in a certain habitat type. The palaeoenvironment has been described in the previous chapters using macro and micro plant remains and sediment analysis, revealing a variety of environment and vegetation types around the site (see Chapter 2). Considering the ecological information, the terrestrial habitats around Tianluoshan are summarized into six types: 1) subtropical evergreen broadleaf and deciduous forests; 2) scrub forests; 3) grasslands, usually locate between scrub forests and waters; 4) freshwater wetlands; 5) river, ponds and reservoir; and 6) seashore. Since the wide distributional species can live in various habitat types, the ones that do not exist in the Lower Yangtze River region are eliminated. For example, Sika deer are primarily forest-dwelling deer in many regions, and can adapt many kinds of environment; but it has been recorded that the subspecies in southern China prefer the lowland areas with high grasses to dense forests at high elevation. Therefore, a score of 0.5 is given to the habitat of grassland,

Table 8.3 MNI and THI weighing for the mammal assemblage from Tianluoshan

	MNI			Habitat type						Behaviour		
Taxon	**Stage 1**	**Stage 2**	**Stage 3**	**Forest**	**Shrub forest**	**Grassland**	**Wetland**	**River**	**Seashore**	**Nocturnal**	**Diurnal**	**Dusk & dawn**
Sika deer	14	47	30	0	0.4	0.5	0.1	0	0	0.4	0.3	0.3
Sambar	6	18	4	0.05	0.3	0.3	0.3	0.05	0	0.4	0.3	0.3
Milu deer	1	1	1	0	0.1	0.3	0.5	0.1	0	0.4	0.3	0.3
Muntjac	14	57	14	0	1	0	0	0	0	0	0	1
Water deer	2	1	1	0	0.1	0	0.9	0	0	0	0	1
Water buffalo	3	7	2	0	0	0.2	0.4	0.4	0	0.6	0.4	0
Pig	6	16	13	0.3	0.4	0.3	0	0	0	0.3	0.3	0.4
Raccoon dog	2	2	1	0.1	0.9	0	0	0	0	1	0	0
Black bear	1	1	0	0.7	0.3	0	0	0	0	0.35	0.35	0.3
Badger	2	4	1	0.3	0.4	0.3	0	0	0	1	0	0
Otter	1	2	2	0	0	0	0.4	0.4	0.2	0.35	0.35	0.3
Marten	0	3	0	0.1	0.4	0.3	0.2	0	0	0	0.4	0.6
Civet	0	1	0	0.1	0.9	0	0	0	0	1	0	0
Macaque	2	8	3	0.1	0.5	0.3	0.1	0	0	0	1	0
Cat	0	0	1	0.3	0.4	0.3	0	0	0	1	0	0
Porcupine	0	1	0	0.2	0.4	0.4	0	0	0	1	0	0
Elephant	0	0	1	0	0.5	0.5	0	0	0	0	1	0
Total	54	169	74	2.25	7	3.7	2.9	0.95	0.2	7.8	4.7	4.5

0.4 to shrub forest, and 0.1 to wetland; no point is given to the habitat of forest. The taxonomic habitat indices of the Tianluoshan fauna are compiled in Table 8.3. The index values of each habitat types are added up for a total number, and then divided by the number of species to produce a cumulative index. The indices of species from three phases are shown in Figure 8.2.

The analysis produced several characteristics. The Tianluoshan fauna shows strong shrub forest elements, followed by the grassland and wetland elements. The elements of forest and rivers are relatively weak comparing the former three environment types, and the seashore element is minor.

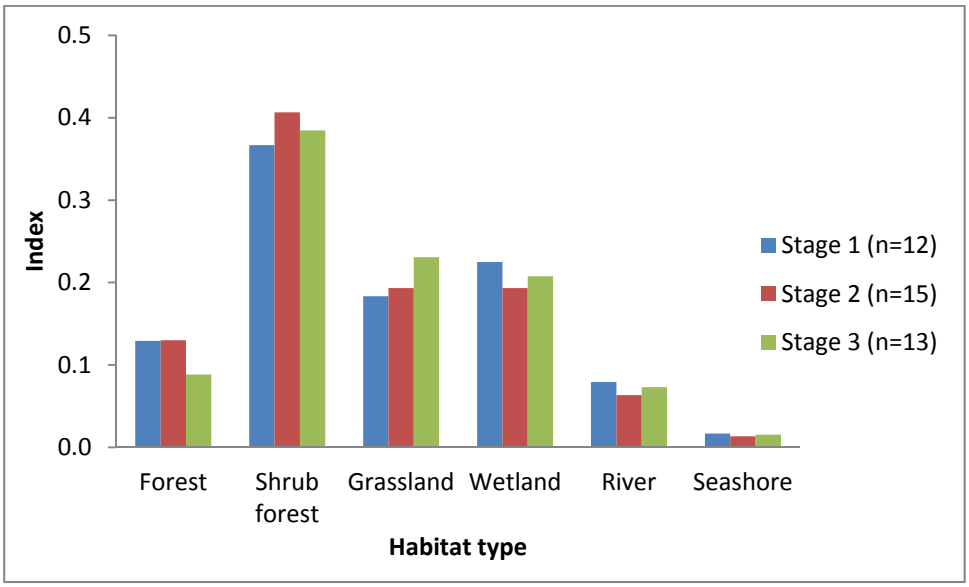


Figure 8.2 Taxonomic Habitat Index (THI) of the Tianluoshan fauna.

The THI values of three phases show very similar distribution patterns, with slight difference between them. Judging from Figure 8.2, sample size may influence the THI distribution. As is presented at the beginning of Chapter 7, Stage 2 has the largest sample size and the number of species (indicated in Figure 8.2), and Stage 1 has the smallest sample size and species number. As the sample size increases, the

predominance of shrub forest becomes more obvious. Moreover, chronological change can be detected in the THI values. The forest element further weakens, whereas the grassland element strengthens significantly. This change can be explained by different reasons, such as the change of climate, human influence on the environment, and methodological reasons.

As summarized in Chapter 2, the climate was warm and humid during the mid-Holocene, but it tended to be temperate and mildly dry since the end of the Hemudu period, and the vegetation could have changed simultaneously. The enhancement of grassland element in Stage 3 of Tianluoshan could be caused by the climatic change at that time. Secondly, the preferred catchments may change as the subsistence economy evolves. For example, catchment analysis suggests that the exploitation range for hunting-gathering is normally within 10 km or 2 hours walking, and the range for an agriculture society is much smaller, only about 5 km or 1 hour waking (Bintliff, 1988). The development of agriculture at Tianluoshan has been discussed before, that rice was gradually cultivated during the Hemudu period. The emergence of rice cultivation might have influenced the shift from farther catchments to the nearer ones. Third, the THI ecological analysis is based on the animals which are brought to the site by human, thus the reconstructed ecology shows strong influence from human's choice. The interrelationship between environment and subsistence economy makes the interpretation complicated, and the palaeo-environment may not be reflected genuinely. Therefore, the THI technique shall be modified to discuss the resource exploitation in the next section.

8.2 The subsistence economy at Tianluoshan: the exploitation of animal and plant resources

After analyzing different the animal remains from Tianluoshan, we can come back to the question which was raised at the beginning of this thesis: what was the subsistence of the Hemudu culture like? Based on the questions that were placed and answered in the analysis progress, the subsistence can be interpreted from the following perspectives: 1) the resource types that were exploited in the subsistence economy; 2) scheduling of various resources; 3) the skills, techniques, and strategy for hunting, gathering, and fishing; 4) food processing.

According to the analysis of range and relative abundance of taxa, a total number of 30 animal species have been identified from the Tianluoshan assemblage so far, including fish, mammals, reptiles, and birds, but only a limited number of them were intensively utilized. These animals can provide important information for interpreting the subsistence strategies at Tianluoshan, and are thus specially focused in this project.

Fish

The number of fish remains is enormous, larger than any other animal remains from Tianluoshan. The fish remains mainly consist of freshwater species, especially the highly adaptive species inhabiting the nearby wetlands: snakehead, crucian carp, and common carp. The presence of head and trunk bones from sampling suggests that fish were probably captured, processed, consumpted, and discarded at site. In addition, a small number of estuarine and marine fish were present at Tianluoshan, indicating diverse fishing grounds were selected.

Mammals

Similarly, selective hunting could be observed from the Tianluoshan mammal remains. Several indigenous deer were the major prey of Tianluoshan inhabitants. They were hunted for meat, hide, antlers, and bones which were important raw materials for making tools, such as the distinctive 'Si' (Chapter 2 and 6). In contrast, *Sus* was merely a supplementary resource at that time, but it became more and more important in the following millennia as pig domestication developed.

Apart from those major hunted resources, the minor mammals captured by the Tianluoshan inhabitants included several species of carnivores which were commonly utilized as prime fur resources by ethnographic groups (Zhao, 1991, P42-52, Song et al., 2008), and monkeys which were also present at the Jomon sites in the Japanese archipelago (Kobayashi, 2004, P75, Tsujino et al., 2010).

Birds and reptiles

Birds and reptiles were also important component in the subsistence. Plenty of fragmented tortoise shells, skeletal parts, and bird bones have been collected during excavation. Small pieces of these remains were retrieved from the deposit samples for fish taphonomic analysis.

In my MA dissertation, three reptiles and four birds were recognized from the animal remains. *Amyda sinensis* (Wiegmann), *Chinemys* cf. *reevesii* (Gray), and *Alligator sinensis* Fauvel were identified to species based on the clear diagnostic features on a few skeletal parts, such as the skulls, carapace, plastron, and limb bones. Goose (*Anser* sp.), duck (*Anas* sp.), and crane (*Grus* sp.) were identified to genus level; a few specimens were recognized belong to Accipitridae. Due to the lack

of a proper reference collection for identifying none-mammalian remains, the reptiles and birds were identified using reference atlases (Wei et al., 1989, Matsui, 2001-2005).

In general, the reptiles and birds found at Tianluoshan at wetland animals. Tortoises and soft-shelled tortoises live in rivers, lakes, and wetlands; they also inhabit land environment, and eggs hatch on land. The Chinese alligators inhabit wetlands, swamps, ponds, lakes, and rivers in subtropical temperate region (Mertz, 2003). They are rare now, but were commonly found in Neolithic sites along the Yangtze River. The birds found at Tianluoshan are mostly migratory bird. They move to Siberia in spring to breed. while wintering, goose and duck frequent lakes, marshes, and pasture lands, and crane prefers marshes and wetlands with wide expanses of fresh water and good visibility (Johnsgard, 1983, Soothill and Whitehead, 1996). Wetland was probably the permenant habitat for these reptiles and the overwinter shelter for the migratory birds.

However, the reptiles and birds represented different resource types in the same wetland. First, both categories required different hunting methods due to their behaviours and escape strategies. These reptiles were slow moving animals which require little technique to catch. On the contrary, birds moved fast and could only be caught with specific tools (traps, bow and arrow, etc.) and techniques (e.g. whistling). Second, reptile was a permenant resource, but birds were seasonal. The catch of both resources infers that reptile hunting might have to be adjusted to adapt to bird hunting and other hunting and gathering activities.

Plants

A limited range of 50 plant species present at Tianluoshan, and 33 of them are

plausibly field weeds of early rice fields (Fuller et al., 2011). Only four food plants, i.e. acorns, water chestnuts, foxnuts, and rice, occur in large quantities, suggesting specialized gathering on the wild resources. These plant remains imply a major seasonal collection focusing on the late summer and autumn (Fuller et al., 2011).

Rice was the one and only domestic species found at Tianluoshan. The non-shattering domesticated rice spikelet bases over the Hemudu period increased from 38% to 51%; the proportion of rice increased from 8% to 24% of all plant remains (Fuller et al., 2009, Fuller et al., 2011). The numbers kept growing during the epi- and final Neolithic phases in the lower Yangtze River region. The Hemudu culture might represent the early phase of agriculture in this region.

To sum up, the animal and plant remains from Tianluoshan imply a complex hunting-gathering-fishing economy focusing on a small number of selective resources. Evidence from animal remains suggested that the development of animal domestication did not parallel with that of plants. The overall analysis on the *Sus* remains indicated that they belonged to wild boars. The stable isotope analysis suggested that the Tianluoshan specimens were more like the Jomon wild boars rather than domestic pigs (Minagawa et al., 2011). Evidence assured pig domestication in the Liangzhu period (Zhang, 2009); thus, the gap between the Hemudu period and Liangzhu period is possibly the key time for the emergence of pig domestication in the lower Yangtze River.

This research proves the assumption that fish was an important component in the subsistence economy of the Hemudu culture. In the Yangtze River region where has rich water resource, the importance of fish in subsistence has always been

proposed but never been demonstrated (Yuan et al., 2008). This assumption was supported by archaeobotanical research that aquatic plants, which were possibly from the same water bodies with fish, were widely used at Tianluoshan (Fuller et al., 2011). The quantification of the fish remains in the Tianluoshan assemblage first provides information for use to evaluate the significance of fish in the subsistence economy. Due to various taphonomic reasons, the number might have been underestimated. Those well preserved fish remains in K3 represent more than 1,500 fish which might be from a fish season or even a single catch, indicating the actual number should be enormous.

The animal remains indicate a fairly sustainable subsistence system at Tianluoshan throughout the millennium of the Hemudu culture; hunting and fishing barely put survival pressure on the wild populations. When hunting pressure increases, it may break the balance of the ecosystem, and cause the prey animal 1) decline in population size, 2) change of proportions of all animals, and 3) change of age structure within the population. However, the Tianluoshan faunal assemblage does not show these changes. First, the fish and mammal species did not change from Stage 1 to Stage 3. Second, the relative proportions of the species generally kept stable through the stages. Slight fluctuation can be detected within the fish assemblage (Chapter 5). The most significant change in proportion is possibly the gradual decrease of the large-sized mammals and the steep increase of medium-sized mammals in the late phase of the Hemudu period (Chapter 7). Third, the body length reconstructions of various fish showed no sign of size reduction or overfishing. At last, the cull patterns of wild boar, sika deer and muntjacs show great similarity

between different stages at Tianluoshan, indicating that protective hunting was organized at site. In brief, the zooarchaeological research suggests an efficient and sustainable subsistence strategy which kept hunting and fishing within the carrying capacity of the environment.

Considering the factors above, the rich resources could have been the holdbacks for animal domestication to commence. The subsistence needs for food and raw materials can be satisfied by hunting.

8.3 Temporal dimensions: scheduling of resource exploitation

Scheduling the exploitation of various resources is an important part of the subsistence economy. Some resources are only available at fixed time in a year, like fruits, nuts, and migratory fish; whilst the others are available throughout the year, but their distribution, the costs and risks of acquiring them, and the quality of their nutrients and by-products may vary between seasons. By scheduling the resource exploitation, we can find out how people cope with fluctuating abundances of edible resources and solve conflicts when several resources are available at the same time.

In addition, the seasonal cycles in resources have significant impacts on the sites and societies. On one hand, they influence where sites are located, when they are occupied, how many people live there, and the activities that occur at them (Reitz and Wing, 2008, P261). On the other hand, they influence the coordination of labour among men and women of different age groups within the society (Gragson, 1993, McGovern, 1994).

Table 8.4 Timetable for the exploitation of the major food resources at Tianluoshan by month, integrating mammals, fish, and plants. The months when people get access to a resource are marked with colour; the ones marked with dark colour refer to intensive resource exploitation. The seasonality of plants are quoted from Fuller et al. (2011).

	J	F	M	A	M	J	J	A	S	O	N	D
Wild boar												
Sika deer												
Muntjac												
Snakehead												
Common carp												
Crucian carp												
Foxnut												
Water chestnut												
Rice												
Acorn												
Fruits												

The cull season of different animals in the Tianluoshan has been analysed in Chapter 5 and 7. The results and the seasonality of plant resources are summarized in Table 8.4. In general, it shows a well-planned scheduling for exploiting different resources in a year. The events are dispersed throughout the year, barely overlapping. In chronological order, intensive fishing seems to have started in early spring, followed by wild boar hunting. Rice sowing possibly occurred in spring as well. Summer seems to have focused on boar hunting, carp fishing, and gathering wild aquatic plants. Rice and acorn harvesting was timed for autumn. Sika deer hunting mostly occurred in winter (Figure 8.3). The fur animals such as raccoon dog, otter,

and marten were probably hunted in winter as well.

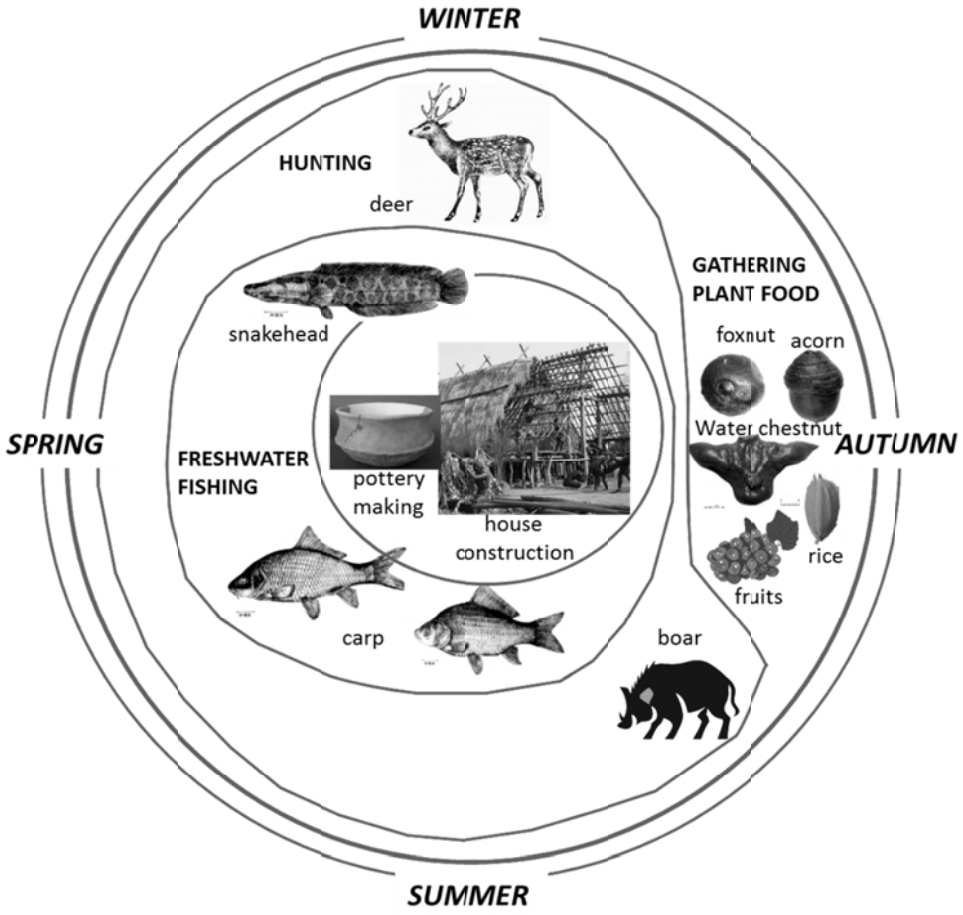


Figure 8.3 The cycle of seasonal resource exploitation at Tianluoshan.

The edible resources from Tianluoshan can be roughly categorized into two groups: seasonal and non-seasonal. Fruits and nuts are highly seasonal resources which can be only collected in fixed seasons of the year. Plus, the fruiting season is usually rather short, so it requires great labour to collect the fruits and nuts before they gets rotten or eaten by animals. For instance, the harvest season of acorns from Tianluoshan is suggested to be from August to November due to lack of species-level identification, and this is the period when the majority of *Lithocarpus* and *Cyclobalanopsis* species in South/Southeast China in fruit (Fuller et al., 2011). In actuality, the peak season for acorn collecting is perhaps 1 to 3 weeks only, as acorns

just begin to fall off trees once come into maturity (Hillman, 2000). There was possibly conflict in the time and labour that were spent on acorn gathering and rice cultivation, and the conflict would eventually become more serious as rice agriculture developed. In the meantime, hunting and fishing only occasionally occurred in autumn. This was probably arranged on purpose to avoid the extremely busy season.

Wild boar, deer, and fish are basically resident animals, and thus are available throughout the year. However, as the risks and returns of acquiring them may differ between seasons, archaeological and ethnographic records indicate that the exploitation of these resources is usually seasonal (i.e. Carter and Magnell, 2007, Habu, 2004, Kobayashi, 2004, Song et al., 2008, Uchiyama, 1999, Zhao, 1991). The body weight of animals usually varies between different seasons. Research on the modern sika deer revealed that sika deer was heaviest in autumn, with a mean body weight of 62.6kg, and would lose a few kilos in winter (mean body weight 57.4kg) (Masuko and Souma, 2009). The body weight in spring and summer is slightly heavier than that in winter. The seasonal body weight increase of boars is even greater, for up to 40 kg from late winter to later summer (Carter and Magnell, 2007). Therefore, concentrating the hunting in autumn when the animals are in prime condition can efficiently maximize the yields, especially meat and fat.

Carter and Magnell (2007) suggested an ideal pattern for optimal hunting, but this may not suit a complex subsistence economy. Ethnographic records of the Oroqen people -- a group of modern hunter-gatherers living in the northeast China -- described that deer hunting occurs in all three seasons of spring, summer, and

autumn (Zhao, 1991, P42-50). In contrast, the Neolithic Jomon people lived on the Japan archipelago hunted sika deer only in winter (Kobayashi, 2004, Habu, 2004). Similarly, the sika deer from Tianluoshan were intensively hunted around early winter. It may not be as profitable as is suggested by the optimal hunting pattern; however, it can increase the overall yield of the resource exploitation by avoiding conflicts with acorn gathering and rice harvesting. The body mass of boar climaxes in late summer, and drops in the forthcoming mating season in autumn. Therefore, wild boar hunting was timed for just before the plant harvesting season.

Fish, which had been readily available in local wetlands throughout the year, was an important stable food resource for the Tianluoshan people. The optimal fishing seasons vary by species due to their life cycles and behaviour patterns. Many fishermen tend to target the fish during reproduction season when they assemble in a small area. Carp and snakehead tend to spawn in shallow and grassy waters, and wetlands and rice field provide the exactly spawning bed for them. When rice-fish farming arise, these highly tolerant fish are chosen for the specific ecosystem (Halwart and Gupta, 2004). Snakehead, on the other hand, is a resident fish which performs distinctive behaviours. Ethnographic records suggest that various simple but efficient fishing methods have been developed targeting specific behaviour of snakehead in different seasons (see Chapter 6). Therefore, snakehead fishing can be practiced at different seasons of the year, depending on the scheduling arrangement.

In general, the highly seasonal resources, in the case of Tianluoshan, plants, constituted the frame of the subsistence timetable, and other resources were adjusted into the available slots, possibly due to labour management. This pattern

might strengthen as agriculture developed and more labour was invested in it. Environment manipulation in relation to rice cultivation might have influenced the habitats for fish, and decided the fishing seasons.

In the early phase of rice agriculture, rice was planted on the margin areas of the wetlands, and there might not be clear boundaries between the natural wetlands and the primitive rice fields. The growth cycle of the early cultivated rice was possibly from spring (beginning of the rainy season) to autumn (dry season). The environment manipulation for sowing rice included land modification and aquatic vegetation clearance, which intruded into the habitat of snakehead. This could be the reason why snakeheads were intensively fished in the early spring instead of during their spawning season from late May to July. As rice plants grew up, they provide shelter for wetland fish. In summer, the dense rice plants attracted fish about to spawn. This might lead to the second fishing season of the year. Fish has been an important by-product in the rice agriculture (e.g. Gregory and Guttman, 1997). Fish do not harm the crops; on the contrary, keeping fish in the rice field can increase the harvest of rice by fertilize the soil and pests control (Halwart and Gupta, 2004). The Tianluoshan people might have been good at manipulating the fish-rice ecosystem to increase the yield of rice and fish.

Interestingly, the wild boar hunting season almost overlaps with the growth period of rice. Until now, wild boars have been well known as agricultural pests all over the world. They usually break into the field and destroy the crops rather quickly. Hunting wild boars can attain the goals of obtaining meat and protect the rice agriculture at the same time. This could have been one of the reasons why wild boar

hunting has been along the development of agriculture. Plus, wild boars prefer starch rich food, especially before the forthcoming breeding season and the lean winter, so they are competitive contenders to people in many wild food resources such as acorns and tubers. Therefore, hunting boar might be a strategy to increase the yield of food gathering.

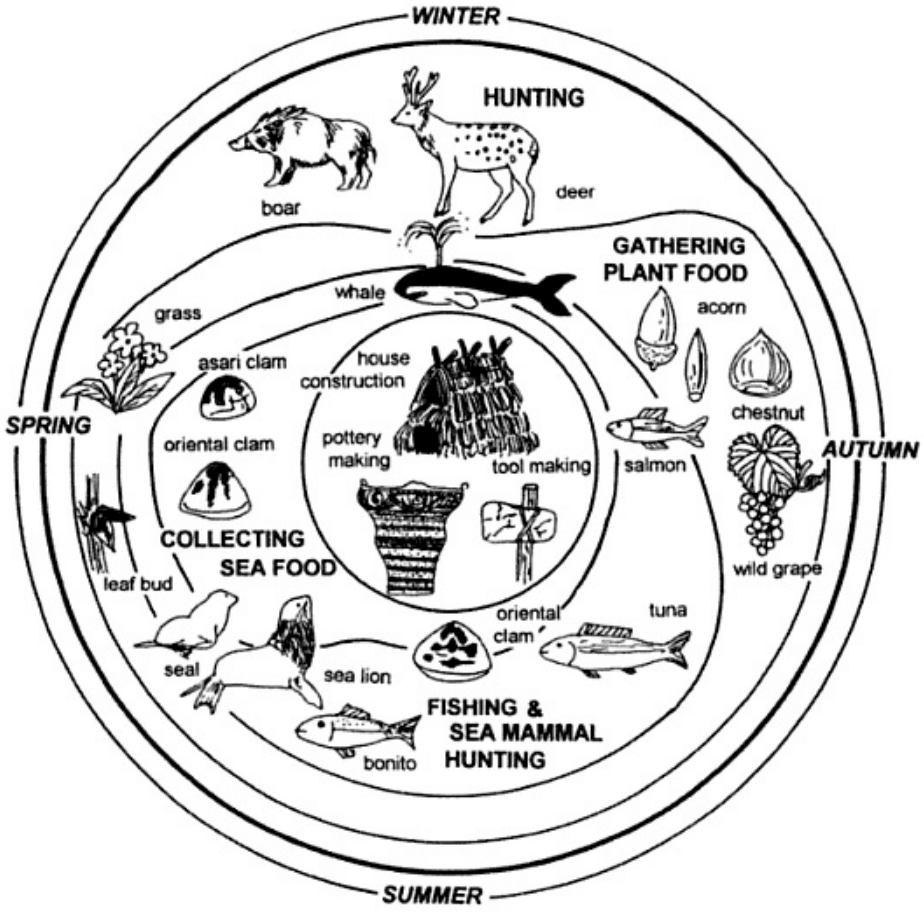


Figure 8.4 The 'Jomon calendar' showing the cycle of seasonal resource exploitation. This directly reference from Habu (2004, Figure 3.1), but the 'calendar' is modified from Kobayashi 1977:158.

The scheduling of Tianluoshan shares some commonalities with the hunting-gathering timetable of the Jomon culture, also known as the 'Jomon calendar' proposed by Kobayashi in 1977 and developed further in 2004. The 'Jomon calendar' shows a cyclical process of hunting, fishing, construction, and pottery production.

Most food resources contained in the ‘Jomon calendar’ are highly seasonal, including nuts, fruits, marine mammals and fish, edible leaves and flowers (Figure 8.4). Within this subsistence structure, resources which are less seasonal, such as sika deer and wild boar, are pursued in the less busy winter season, although it cannot make the best yield from hunting.

Strategically, the greatest difference between the Tianluoshan scheduling and the Jomon calendar is the wild boar hunting season. The Jomon culture was a completely hunting-gathering culture, whilst agriculture emerged in the Hemudu culture. Boar hunting at Tianluoshan might be a strategy for both meat acquisition and pest control for rice cultivation, implying that animal use (fish and wild boar) must harmonize with farming schedules. Hopefully we will find out whether this connection between rice and wild boar eventually stimulated the emergence of pig domestication.

To sum up, it requires broad knowledge about animal habits, behaviours, life history, the environment, and the ecosystem to establish an efficient and sustainable schedule for hunting, fishing, and gathering events. The intensified exploitation of varied resources was arranged at different time of year to avoid conflicts in labour and time. However, the exploitation season of certain resources seemed to be related judging from the ecological and cultural background. Rice cultivation might have influenced the scheduling of other resources. As rice farming became more and more important in the cultures thereafter, the scheduling strategy might have changed accordingly. This hypothesis needs more evidence from the sequential sites in the same region. This will be the next research question in the near future.

8.4 Spatial dimensions of resource exploitation

The paleo-ecology around Tianluoshan is reconstructed using the THI technique earlier in this chapter. It generally shows the distribution of different habitat types in the environment around the site of Tianluoshan. As the paleo-ecology reconstruction is based on the analysis of the animals which were brought to the site by the inhabitants, it also indicates the hunting strategies, especially the geographic range of hunting ground, and its change along with subsistence economy.

This section attempts to interpret the resource exploitation at Tianluoshan on the basis of THI analysis. Apart from the dietary resources, non-dietary resources have significance for the settlement, such as the construction materials. As this research is centred on the interpretation of subsistence economy, the dietary resources, both animal and plant resources, are concerned primarily. Considering the difference between quantifying zooarchaeology and archaeobotany, the resources shall be analysed respectively. Fish and mammals are also separated during quantification.

8.4.1 Spatial exploitation of mammalian resources

According to the THI method, the relative abundance of animals is not included during the analysis of the paleo-ecology. Nevertheless, the number of animal is meaningful in zooarchaeological study, indicating the importance of a resource in the subsistence economy, and it may reflect the intensity of resource exploitation in a certain habitat type. When an animal is hunted repeatedly, it means that its living habitat type is exploited extensively, and the index value for this habitat type shall be higher.

The composition of the fish and mammalian assemblages is revealed in previous

chapters. Both assemblages consist of one or a few predominant species and a serial of less important species. We can assume that the habitats of the predominant species shall be exploited more extensively than the others. As each species has complex habitats, it cannot be thoroughly interpreted by normal methods; but the index values of the THI technique can solve this problem.

The general idea of this process is to integrate the MNI with THI values, and then use the indices to evaluate the exploitation to different habitat types. The introduction of MNI may lead to a different result from Andrews' THI method. The procedures shall be listed as follows.

The first step is to multiply MNI values, which are given in Table 8.3, to the corresponding THI values of a species. The calculated scores of three stages are given in Table 8.5. Second, calculate the sum of the scores under each habitat type, and get a number. Take Stage 1 for example, shrub forest scores 28 by adding Sika deer (0.4×14), sambar (0.3×6) etc., until macaque (0.5×2). At last, the total score of a habitat type is divided by the total MNI of the stage to produce a cumulative index (t). The calculation procedure can be expressed by a formula:

$$\mathrm{t} = \sum_{i=1}^{n} THI_n \times MNI_n \Big/ \sum_{i=1}^{n} n$$

Therefore, the cumulative index for the shrub forest in Stage 1 is 28÷54=0.52. The index values of the six habitat types from three stages are shown in Table 8.5, and they can be expressed by Figure 8.5.

Table 8.5 The habitat indices of three stages at Tianluoshan, by multiply THI by frequency (MNI).

	Stage 1						Stage 2						Stage 3					
Taxon	**Forest**	**Shrub-forest**	**Grass-land**	**Wet-land**	**River**	**Sea-shore**	**Forest**	**Shrub-forest**	**Grass-land**	**Wet-land**	**River**	**Sea-shore**	**Forest**	**Shrub-forest**	**Grass-land**	**Wet-land**	**River**	**Sea-shore**
Sika deer	0	5.6	7	1.4	0	0	0	18.8	23.5	4.7	0	0	0	12	15	3	0	0
Sambar	0.3	1.8	1.8	1.8	0.3	0	0.9	5.4	5.4	5.4	0.9	0	0.2	1.2	1.2	1.2	0.2	0
Milu deer	0	0.1	0.3	0.5	0.1	0	0	0.1	0.3	0.5	0.1	0	0	0.1	0.3	0.5	0.1	0
Muntjac	0	14	0	0	0	0	0	57	0	0	0	0	0	14	0	0	0	0
Water deer	0	0.2	0	1.8	0	0	0	0.1	0	0.9	0	0	0	0.1	0	0.9	0	0
Water buffalo	0	0	0.6	1.2	1.2	0	0	0	1.4	2.8	2.8	0	0	0	0.4	0.8	0.8	0
Pig	1.8	2.4	1.8	0	0	0	4.8	6.4	4.8	0	0	0	3.9	5.2	3.9	0	0	0
Raccoon dog	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Black bear	0.2	1.8	0	0	0	0	0.2	1.8	0	0	0	0	0.1	0.9	0	0	0	0
Badger	0.7	0.3	0	0	0	0	0.7	0.3	0	0	0	0	0	0	0	0	0	0
Otter	0.6	0.8	0.6	0	0	0	1.2	1.6	1.2	0	0	0	0.3	0.4	0.3	0	0	0
Marten	0	0	0	0.4	0.4	0.2	0	0	0	0.8	0.8	0.4	0	0	0	0.8	0.8	0.4
Civet	0	0	0	0	0	0	0.3	1.2	0.9	0.6	0	0	0	0	0	0	0	0
Macaque	0	0	0	0	0	0	0.1	0.9	0	0	0	0	0	0	0	0	0	0
Cat	0.2	1	0.6	0.2	0	0	0.8	4	2.4	0.8	0	0	0.3	1.5	0.9	0.3	0	0
Porcupine	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0.4	0.3	0	0	0
Elephant	0	0	0	0	0	0	0.2	0.4	0.4	0	0	0	0	0	0	0	0	0
Total	3.8	28	12.7	7.3	2	0.2	9.2	98	40.3	16.5	4.6	0.4	0	0.5	0.5	0	0	0
THI	0.07	0.52	0.24	0.14	0.04	<0.01	0.05	0.58	0.24	0.1	0.03	<0.01	0.07	0.49	0.31	0.10	0.03	<0.01

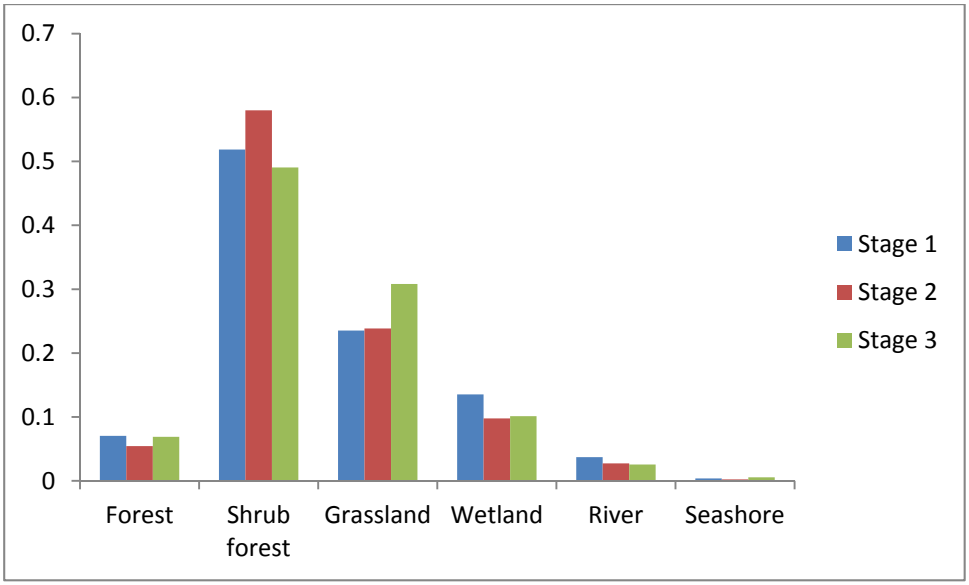


Figure 8.5 The taxonomic habitat index of six habitat types at Tianluoshan, integrated with the MNI values.

Figure 8.6 The modern landscape of Tianluoshan, showing the landforms and vegetation around the site. The main excavation area is covered underneath the dome (photographed by Guoping Sun).

The THI values in Figure 8.5 reveal the exploitation intensity of mammal resources to the six habitat types and the change through time. On one hand, the statistics indicate that the entire environment have been exploited during the

occupation of the site. On the other hand, the resource exploitation is unequal between different habitat types. First of all, it shows an absolute predominance of the shrub forest element, with an index value over 0.5, which is even more protruding comparing to that in Figure 8.2 due to the integration of MNI. It indicates that shrub forest is the prime hunting ground among all the environments. The grassland element comes second, with an index value about 0.25; and the index value for wetland is about 0.1. The other three habitats are only occasionally exploited.

All three stages at Tianluoshan have similar distributional pattern, but the index values indicate change of resource catchments through time. From Stage 1 to Stage 2, the wetland index declines while shrub forest increases markedly. The index value of shrub forest drops again for nearly 0.1 when coming to Stage 3, whereas the index value of grassland increases for 0.07. It also indicates the change of resource exploitation range in the Hemudu period. According to the environmental reconstruction by Mo, Qin, and colleagues (Mo et al., 2011, Qin et al., 2010), Tianluoshan is located in a narrow valley along the Yao River, and the habitat types distribute around Tianluoshan concentrically (also see Figure 2.2 and Figure 2.3). From near to far, the habitat types are wetland, grassland, and shrubs, which can be recognized from Figure 8.6. The forests, including coniferous forests, mixed subtropical evergreen and deciduous broadleaved forests, can be found on mountains several kilometres away from Tianluoshan, whereas the shrub forest, which is a major hunting ground for the mammal food resources, is much close to the settlement, approximately within two kilometres. Therefore, the first shift can be

seen as an expansion of exploitation range, that more hunting are practiced in the shrub woods rather than wetlands. The second shift refers to a range shrink that people tend to rely more on the resources close to the settlement.

What are the motives behind these changes? Apart from the environmental issues which are presented previously, social issues may have played strong influence in the process. The reason for the expansion of exploitation range is relatively simple, that it probably indicates the increase of food demand as the settlement develops and population increases. As population density increases and territory contracts, the Tianluoshan people may have been forced to rely more on local resources, such as cultivated rice to replace further wild fruits (Fuller et al., 2011). Plus, the proportion of domesticated rice has increased over time (Fuller et al., 2009), showing the gradual development of agriculture at Tianluoshan during the Hemudu period. In general, the catchment range for an agriculture settlement is smaller than that of a hunting-gathering settlement (Bintliff, 1988). Although there has not been assured evidence for animal domestication at that time, the decrease of exploitation range is possibly due to the shift from hunting-gathering to agriculture.

Methodologically, the analysis proves that the integrated THI technique is different from Andrews' THI technique, and can be used to interpret resource exploitation. The original THI by Andrews is an ecological value based on the presence or absence and the habitats of a species. The integration with the frequencies of animals makes the THI a zooarchaelogical value, which is dependent on the relative importance of the animals in the faunal assemblage. If a habitat type is exploited extensively, it shall be reflected by its index value. Since the exploitation

intensity of each habitat is transferred into index value, this method makes the comparison between different resources available, such as mammals, fish, and plants, using the same calculation process; but each category should be treated separately due to their different quantification methods.

8.4.2 Resource exploitation at Tianluoshan: an integration with ichthyarchaeology and archaeobotany

This section attempts to use the THI method to interpret the exploitation of fish and plants, and discuss the resource exploitation by integrating all animal and plant resources. There will be three parts of analysis: fish, seeds, and wood, each analysed individually.

8.4.2.1 The THI analysis of fish and plant remains

The ecological information and MNI of the predominant fish species have been presented in Chapter 5. Their habitats are generally divided into wetland (shallow, sluggish, and anaerobic water), river (deeper and running water), and sea (sea water). For the convenience of analysis, the estuary is classified into the 'river' category. Same as analyzing mammalian species, each habitat type of a fish species is given a score, and the sum of the scores is '1' for a species. The THI values and the MNI data are summarized in Table 8.6.

Following the process, the MNI-integrated THI value of each habitat type is calculated, and the results are shown in Figure 8.7 (b). The dominance of the wetland habitat is very obvious, with a THI value of 0.8 and over. This result indicates that the wetlands around the site were probably the main fishing place.

Table 8.6 MNI and THI weighing for the fish assemblage from Tianluoshan. The THI values are summarized from the habitat description in Chapter 5.

Taxon		MNI				Habitat type					
		K3	Stage 1	Stage 2	Stage 3	Forest	Shrub forest	Grassland	Wetland	River	Seashore
Snakehead	*Channa argus*	58	840	2220	179	0	0	0	0.95	0.05	0
Catfish	*Parasilurus asotus*	19	69	84	7	0	0	0	0.7	0.3	0
Common carp	*Cyprinus carpio*	146	166	167	44	0	0	0	0.8	0.2	0
Crucian carp	*Carassius carassius*	1431	193	67	15	0	0	0	0.8	0.2	0
Sea bass	*Lateolabrax japonicus*	0	26	27	13	0	0	0	0	0.8	0.2
Culter	*Culter alburnus*	0	28	21	5	0	0	0	0.3	0.7	0

Table 8.7 The main wild resources and rice through the three phases of Tianluoshan, and specimen count based on 28 sieved samples. The statistics are quoted from Fuller and Qin (2010).

Taxon		MNI			Habitat type					
		K3	Stage 1	Stage 2	Forest	Shrub forest	Grassland	Wetland	River	Seashore
Acorn	Cyclobanopsis/Lithocarpus	2714	42.6	11.7	1	0	0	0	0	0
Water chestnut	*Trapa cf. natans*	696	523	262	0	0	0	1	0	0
Foxnut	*Euryale ferox*	231	52.5	6.66	0	0	0	1	0	0
Sedge nutlets	All Cyperaceae	42.5	9.96	5.42	0	0	0	1	0	0
Peach stone	*Amygdalus cf. Davidiana/persica*	0.025	0	0	1	0	0	0	0	0
South sour jujube	*Choerospondias axillares*	0.5	1.04	0.020	1	0	0	0	0	0
Persimmon	*Diospyros* sp.	20	0.546	0.385	1	0	0	0	0	0
Kiwi	*Actinidia* sp.	0	0.845	2.55	1	0	0	0	0	0
Grape	*Vitis* sp.	0	0.107	0	0	1	0	0	0	0
Bramble	*Rubus* sp.	0	1.27	0.659	0	1	0	0	0	0
Paper mulberry	*Broussenetia* sp.	0	0.214	0	1	0	0	0	0	0
Fig	*Ficus* sp.	0.524	0	0	1	0	0	0	0	0
Chinese hop	*Humulus scandens*	0.264	0.189	0.927	0	0	0	0	0	0
Rice grains & fragments	*Oryza*	592.62	155.17	167.34	0	0	0	1	0	0
All seeds/fragments		4297.433	787.441	457.661						

Table 8.8 The ratio of the wood through the three phases of Tianluoshan, reproduced from Suzuki et al. (2011).

Taxon	Ratio %	Taxon	Ratio %
Pistacia chinensis	12.6	*Zelkova*	0.6
Cinnamomum camphora	11.1	*Dalbergia*	0.6
Sabina	10.7	*Phellodendron*	0.4
Quercus subgen. Cyclobalanopsis	6.6	*Prunus*	0.4
Lauraceae sp. A	6.3	*Euonymus*	0.4
Salix	5.6	*Castanea crenata*	0.3
Quercus sect. Prinus	4.8	*Carpinus sect. Eucarpinus*	0.3
Morus	4.5	*Aralia*	0.3
Sapindus mukorossi	4.2	*Toona sinensis*	0.3
Viburnum	3.4	*Albizia*	0.3
Aphananthe aspera	3.2	*Ginkgo biloba*	0.1
Platycarya strobilacea	2.8	*Acanthopanax*	0.1
Cleyera	2.0	*Styrax sp.A*	0.1
Lauraceae sp. D	1.7	*Styrax sp.B*	0.1
Lauraceae sp. B	1.4	*Acer*	0.1
Ulmus	1.3	*Xylosma japonica*	0.1
Liquidambar	1.3	*Hovenia*	0.1
Pinus	1.3	*Sapium*	0.1
Quercus sect. Aegilops	1.1	*Choerospondias axillaris*	0.1
Lauraceae sp. C	0.8	*Chionanthus retusa*	0.1
Camellia	0.8	*Cornus*	0.1
Cudrania	0.8	*Osmanthus*	0.1
Celtis	0.7	unidentified	4.7
Diospyros	0.7		

Similar process is also processed on plant remains, seeds and wood separately. Plant is the key factor in defining different habitats in this project, therefore, the THI value for a habitat type is either ‘1’ or ‘0’, indicating this plant exist in this habitat or not. The specimen count represents the exploitation intensity of this plant resource. The THI values and specimen count are listed in Table 8.7, and the final result of the analysis is shown by Figure 8.7 (c).

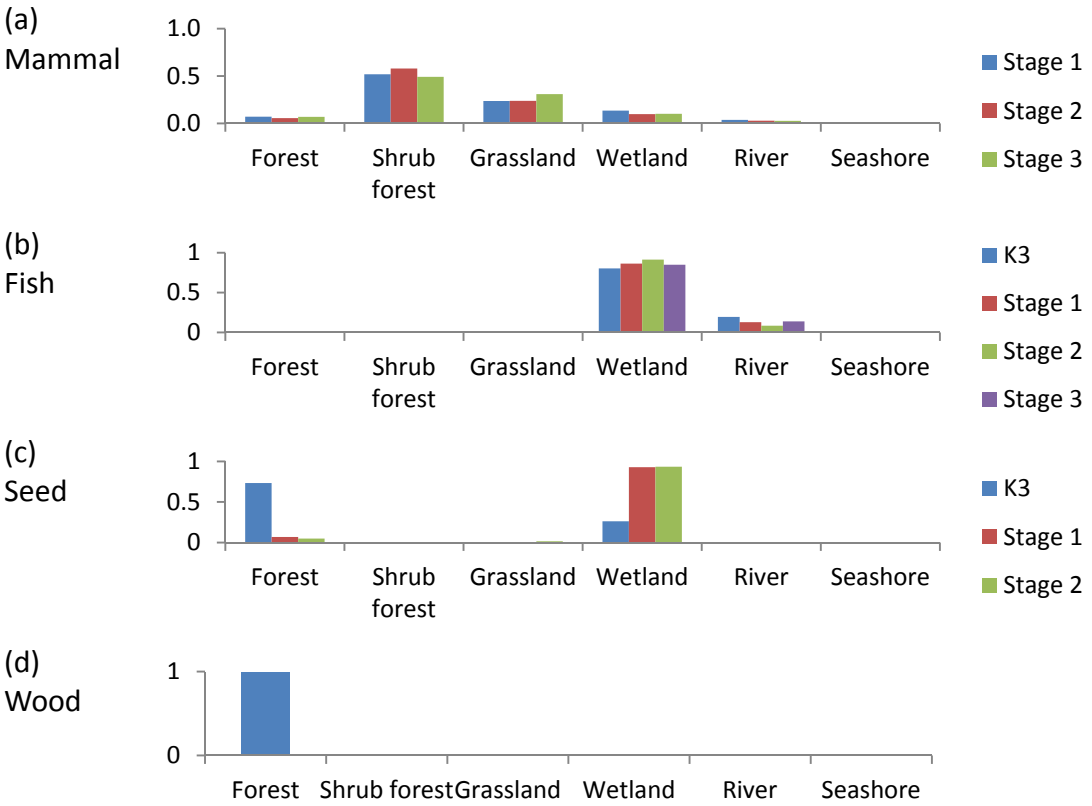


Figure 8.7 Resource exploration at Tianluoshan, including mammals (a), fish (b), seeds (c) and wood (d), which are derived and listed separately. The results of seeds and wood are reproduced from the dataset by Fuller *et al* (Fuller and Qin, 2010, Fuller et al., 2011) and Suzuki *et al* (2011).

The histogram shows great shift about the locations of resource exploitation from K3 to Stage 2. The forest element drops steeply from K3 to Stage 1; meanwhile, the wetland element increases by the same scale. The statistics in Table 8.7 reveal that the sudden decline of the forest element is mainly caused by the acorns. It has been introduced in Chapter 2 that K3 is a single trench (10m×5m) at the edge of the main excavation area (Figure 2.10), and several storage pits filled with acorn shells were found in it underneath the early strata. Radio carbon dates suggested those layers in K3 were even earlier than Stage 1. The partial reveal and the small sample size of K3 might have influence on the result. In general, the result indicates that wetland resources replaced acorns to become the major seed resource.

The species and ratios data of wood in Table 8.8 reference from the research by Suzuki et al. (2011). The result indicates that they represent the forest habitat (Figure 8.7 d). Qin and colleagues (2010) also pointed out that different species of oaks were carefully avoided when collecting raw wood materials.

8.4.2.2 The range and locations of resource exploitation

According to the THI analysis, different resources come from different part of the environment around Tianluoshan. Wood materials for construction and making vessels are transported to the site from forests. Acorns are also collected from the forest (Figure 8.7 (c) K3), but this resource only predominant in the very early phase of the Hemudu Period. Its primary position is replaced by common wetland plants since Stage 2, such as water chestnut, foxnut and rice. Wetland is also the origin of the majority of fish rather than river or seaside. In contrast, mammals are retrieved from more diverse environment, ranging from forests to seashore, possibly due to the mobility of mammals.

In order to interpret the resource exploitation visually, the main resources, including mammals, fish, aquatic plants, acorns, and wood, are plotted in the reconstructed vegetation map by Qin and colleagues (Figure 8.8). For the purpose of observation, the resources are only plotted at their nearest habitat to the Tianluoshan site. Due to the diverse environments around the sites, these closest locations are mostly grouped along the narrow valley where Tianluoshan and other sites are situated, possibly within a few hours' walking. The source for wood raw materials is further in the higher mountains, and so are several fruits.

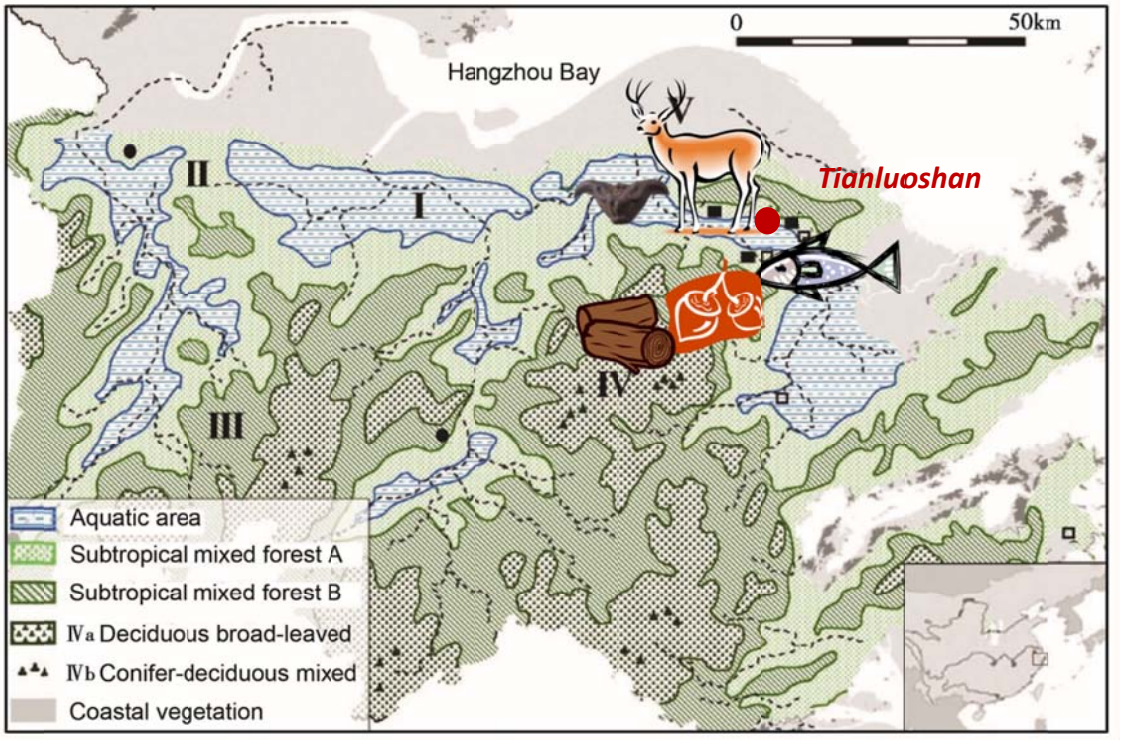


Figure 8.8 Resource exploitation in the environment with reconstructed vegetation according to Qin et al. (2010). The resources are placed at the nearest possible environments to Tianluoshan.

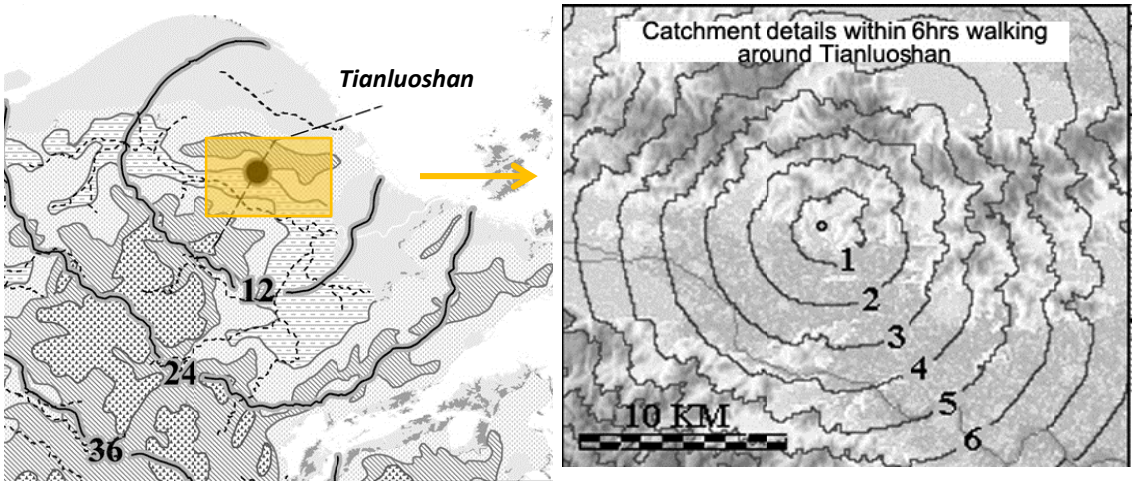


Figure 8.9 The catchment and estimated resource distribution around Tianluoshan with range by walking hours marked. The resources are only shown at the nearest possible locations to Tianluoshan.

Here I will use the detailed catchment simulation by Qin and colleagues to illustrate the range of resource exploitation around Tianluoshan. Geographically, wetland is the closest habitat to the settlement, basically within three hours' walking

or even less (Figure 8.9). From the wetlands outwards, there are grassland, shrub forest, river and other freshwater bodies. Estimating from the simulation, these habitats are probably within six hours' walking. The forests are approximately 12 to 24 hours away from the site. By plotting the resources in the map we can find out that the food for routine consumption, such as fish and mammals, was mostly from the catchments close to the site, e.g. grassland and shrubs. The highly seasonal food, such as seeds and fruits, could be collected from the catchments slightly further.

8.5 Calorific importance of fish versus mammals

How much meat did fish and mammal provide? The total amount of each can be estimated using MNI and the mean weight of each species. The estimation in this thesis aims to have a general idea about the consumption of both categories of animal, so the results will not be very accurate. For example, fish continuously grow throughout their life, and unlike body length, body weight is a three dimentional value, so it is more complicated and inevitably inaccurate to estimate the body weight from the size of skeletal part (Chapter 3). In this thesis, I assume the body weight of the fish with the mean length is the mean weight, and the value is taken from modern faunal records. The statistics are listed in Table 8.9.

Figure 8.10 shows changes of meat weight proportions of each taxon through time. There is a clear decline of large mammals from Stage 1 to Stage 3, including water buffalo and sambar. Conversely, the relative importance of medium sized mammals such as sika deer and pig (wild boar) increases. Sika deer and pig take up about 70% of meat weight in Stage 3, indicating the major meat resource.

Table 8.9 Estimated total weight of Stage 1, 2, and 3, calculated using MNI and mean weight of each taxon. The values of mean weight are estimated from zoological records (Animal Diversity Web, Editorial Committee of Fauna of Zhejiang 1991, Sheng 1992, Sheng et al 1998).

	MNI			Mean weight (kg)	Total weight (kg)					
Taxon	Stage 1	Stage 2	Stage 3		Stage 1	%	Stage 2	%	Stage 3	%
sika	14	47	30	120	1680	30.2	5640	36.5	3600	50.6
sambar	6	18	4	160	960	17.2	2880	18.6	640	9.0
milu	1	1	1	175	175	3.1	175	1.1	175	2.5
muntjac	14	57	14	13	182	3.3	741	4.8	182	2.6
water deer	2	1	1	15	30	0.5	15	0.1	15	0.2
water buffalo	3	7	2	400	1200	21.5	2800	18.1	800	11.3
pig	6	16	13	120	720	12.9	1920	12.4	1560	21.9
snakehead	840	2220	179	0.5	420	7.5	1110	7.2	89.5	1.3
common carp	166	167	44	1	166	3.0	167	1.1	44	0.6
crucian carp	193	67	15	0.2	38.6	0.7	13.4	0.1	3	0.0
TOTAL					5571.6		15461.4		7108.5	

Table 8.10 Relative importance of meat weight in each habitat type. Values are calculated using MNI and THI of each taxon.

	Stage 1					Stage 2					Stage 3				
Taxon	**Forest**	**Shrub forest**	**Grass land**	**Wet land**	**River**	**Forest**	**Shrub forest**	**Grass land**	**Wet land**	**River**	**Forest**	**Shrub forest**	**Grass land**	**Wet land**	**River**
sika	0	672	840	168	0	0	2256	2820	564	0	0	1440	1800	360	0
sambar	48	288	288	288	48	144	864	864	864	144	32	192	192	192	32
milu	0	17.5	52.5	87.5	17.5	0	17.5	52.5	87.5	17.5	0	17.5	52.5	87.5	17.5
muntjac	0	182	0	0	0	0	741	0	0	0	0	182	0	0	0
water deer	0	3	0	27	0	0	1.5	0	13.5	0	0	1.5	0	13.5	0
buffalo	0	0	240	480	480	0	0	560	1120	1120	0	0	160	320	320
pig	216	288	216	0	0	576	768	576	0	0	468	624	468	0	0
snakehead	0	0	0	399	21	0	0	0	1054.5	55.5	0	0	0	85.025	4.475
common carp	0	0	0	132.8	33.2	0	0	0	133.6	33.4	0	0	0	35.2	8.8
crucian carp	0	0	0	30.88	7.72	0	0	0	10.72	2.68	0	0	0	2.4	0.6
TOTAL	264	1450.5	1636.5	1613.18	607.42	720	4648	4872.5	3847.82	1373.08	500	2457	2672.5	1095.625	383.375
Index	0.05	0.26	0.29	0.29	0.11	0.05	0.30	0.32	0.25	0.09	0.07	0.35	0.38	0.15	0.05

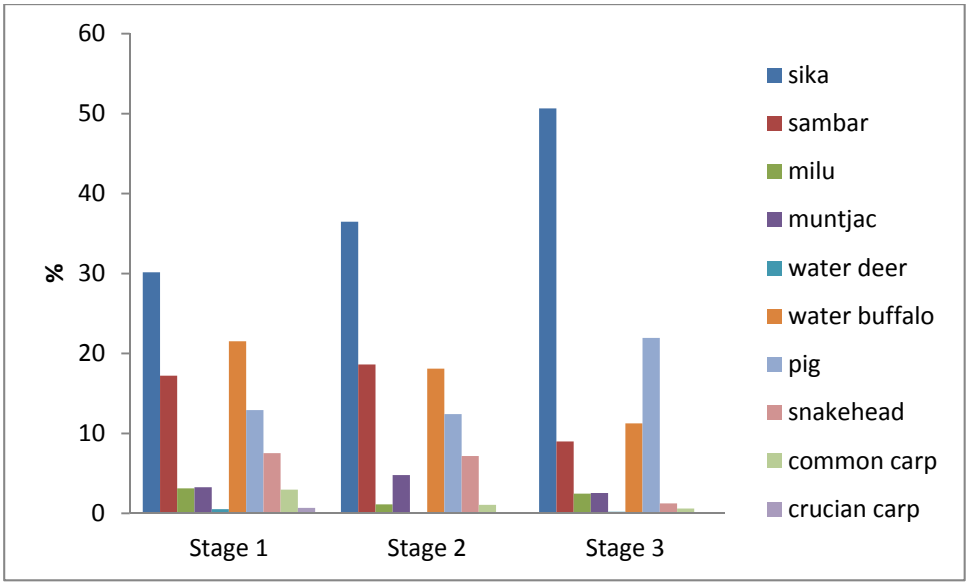


Figure 8.10 Relative importance of meat weight in Stage 1, 2, and 3, integrating mammals and fish.

Although fish have the largest MNI numbers, they only provide 8 – 10 % meat weight, and this percentage falls steeply in Stage 3. The sampling experiment in Chapter 5 shows that fish remains from Stage 3 were severely influenced by taphonomic factors. Therefore, the importance of fish in Stage 3 is still not clear until more samples come out.

The index for relative importance of meat weight in each habitat type is calculated following the procedure in Section 8.4.2, by multiplying the THI score by MNI of each taxon. The distribution is shown in Figure 8.11, which displays similarity with the distribution in Figure 8.7 and the analysis in the previous section. In general, meat mainly comes from the shrubforest, grassland, and wetland throughout the occupation at Tianluoshan. Same as suggested in the previous analysis, the Tianluoshan people barely use marine resources. However, the relative proportions change greatly from Stage 1 to Stage 3. The exploitation of terrestrial areas including forest, shrubforest, and grassland increases, while the use of aquatic areas such as

wetland and rivers drops, especially in Stage 3. This change is caused by the decrease of large mammals such as water buffalo and sambar which inhabit near water (Figure 8.3). A water buffalo can provide almost a thousand times more meat than a wetland fish, so the decrease of these animals influences the results distinctly.

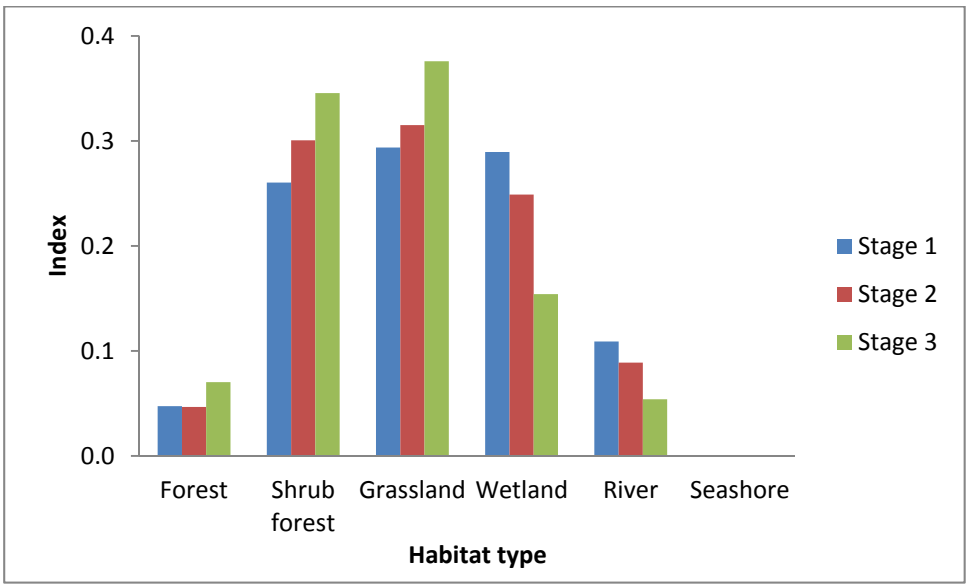


Figure 8.11 Relative proportions of meat weight of different habitat types, integrating THI.

Summarising the discussions in Chapter 6, 7, and 8, Stage 2 at Tianluoshan seems to be the phase of change. During this period, more whitefish are captured and the proportion of blackfish decline (Chapter 6); in the mammal assemblage, the species richness become greater (Chapter 7). In Section 8.8 of this chapter, the analysis of pig bone chemistry suggests that pig-feeding possibly occurres in Stage 2 as well. However, the time of animal use change differs from that of plants. The increase of rice and domesticated rice proportion startes in Stage 1 and continue in Stage 2. More research materials are required to investigate the connections between these two groups of remains.

8.6 Strategy, skills, and technique

The animal subsistence strategies can be inferred from both artefacts and animal remains. In general, the tools in direct relation to fishing and hunting are quite simple, only containing stone arrow heads and stone balls two categories (Sun, 2011), indicating that projecting was the common method to catch animals. In addition, the tools which might be related to fishing and hunting include wooden paddles and bone spade (see discussion in Chapter 6). A large number of tools were uncovered from Hemudu, and had been well studied. Due to the cultural similarities between Tianluoshan and Hemudu, the materials from Hemudu provide supporting evidence to interpret the hunting skills and strategies.

Tianluoshan has the same types of tools as Hemudu does. Qin and colleagues (2006) quantified different tools from the Hemudu site, and found out that bone arrow heads on average made up 60% of the bone and antler tools (Figure 8.12), reflecting the importance of fishing and hunting in the subsistence economy of the Hemudu culture. The proportion of bone spaded was about 8-9%. Bone whistles or flutes, with a percentage of 5%, were also considered to be used for hunting (Zhejiang Provincial Institute of Cultural Relics and Archaeology, 2003). Ethnographic literature of the Oroqen people and native Indians have recorded deer hunting methods by whistling to imitate the distress calls of the young (Anderson, 2005, P46, Zhao, 1991, P42-52). Apart from the projectile points, the possibe fishing tools are much rarer. Only two bone harpoons and one stone net sinker were uncovered from Hemudu, whilst at Tianluoshan, nothing like them has been found.

Clearly, the material culture does not provide enough evidence for investigating

the fishing and hunting strategies. The materials indicate that animals were mostly captured by shooting. This conclusion tallies with the result from the cull pattern analysis of sika deer, which suggests hunting techniques targeting single animals, such as with a bow and arrow, were used (Chapter 7). In addition, it is interesting that the hunting tools from Tianluoshan and Hemudu are made from bone and antler; no stone projectile points have been found. This is perhaps another diagnostic feature of the Hemudu culture apart from the various bone/antler tools and ornaments. It also implies the possibility that deer hunting will play an important part in the subsistence because of the demand for quality raw materials. In this point, domesticated pig can never take its place.

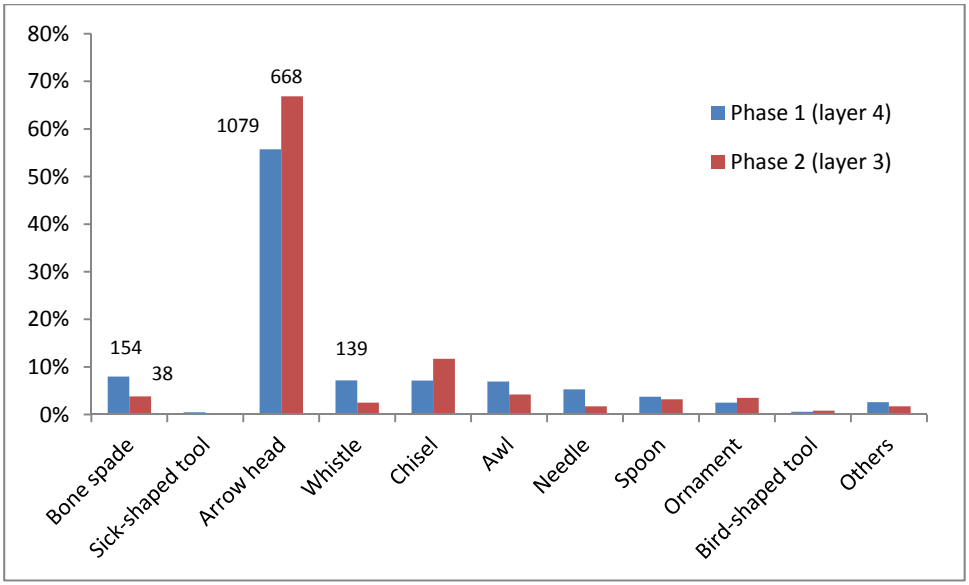


Figure 8.12 Relative proportions of the bone and antler tools from Hemudu, reproduced from Qin et al. (2006). The numbers of the fishing/hunting related tools are marked.

Projectile weapons might be also used for fishing judging from the material culture evidence and ethnographic records. Taking the Oroqen people for example, the fishing tools included harpoon, bow and arrow, fish barrier, and wooden club (beat fish in shallow water directly); they also caught fish with bare hands.

Meanwhile, netting fish was only introduced very recently (Zhao, 1991, P42-52, Song et al., 2008).

Fish remains have provided much information to deduce the fishing techniques and strategies. First of all, an overall analysis of the fish remains and environmental research suggest fishing was mostly practiced in the wetlands. Due to the special features of wetland, the confirmation of fishing location has narrowed the fishing techniques down to a few choices. In addition, ethnographic records provide examples of wetland fishing, helping to define which tools could have been used at Tianluoshan. Many of the examples are made of organic materials like wood, split bamboo, sedge, reed, and netting. It is notable that many stone tools for woodworking have been uncovered from Tianluoshan (Sun, 2011) , indicating the capability of making fishing gears. Although Tianluoshan has not got any evidence for netting tools, it was proved by the findings from Hemudu (Zhejiang Provincial Institute of Cultural Relics and Archaeology, 2003). This is possibly the reason why little evidence for fishing methods was left at the Hemudu culture sites. Most importantly, the body length reconstruction of fish reveals a significant size selection which may be caused by certain fishing strategies.

Fishing is a complicated subsistence activity which involves various tools, techniques, and strategies. Strategically, there is no clear boundary between fishing and hunting. Many methods are known in both fishing and hunting, such as spearing, harpooning, shooting, and trapping (Gabriel et al., 2005, P2). The comprehensive analysis of the fish remains, artefacts, and environment suggests that a variety of size selective fishing methods adaptive to the wetland environment were probably

applied at Tianluoshan. The specific techniques might include trapping, scooping, and using falling gear. Most of the fishing tools involved were possibly made of plant materials.

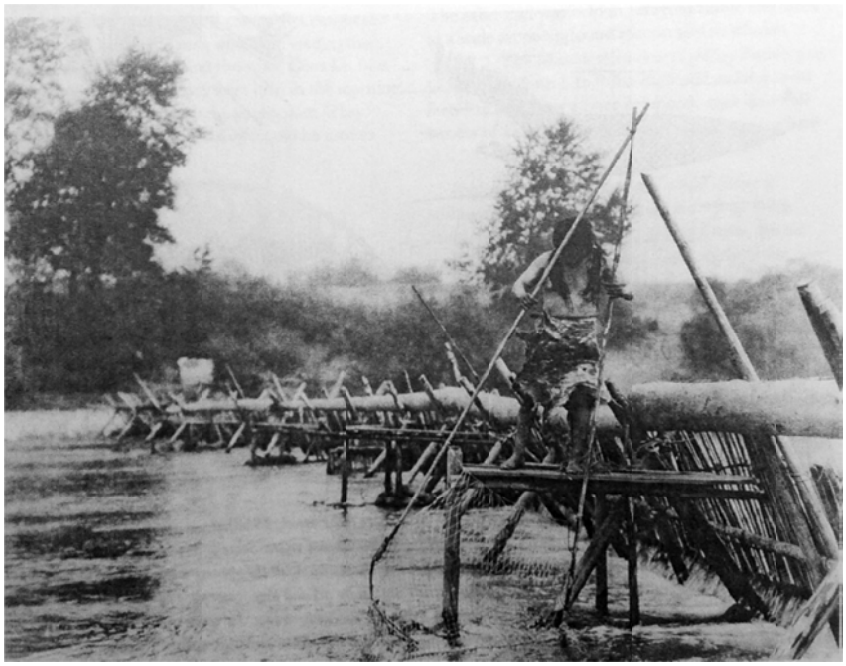


Figure 8.13 Fishing weir built by Native Americans (Campbell, 1999).

This analysis may push us to reconsider the function of some structures in the settlement. Figure 2.12 and 2.13 show a 'T' shaped feature which is interpreted as a fence and log-bridge structure separating the settlement and the outside (Sun, 2011). This feature is located in the most low-lying area of the site. However, it is proposed here that the structure of this feature may be more likely to be a fishing barrier, like the one used by Native Americans (Figure 8.13). Hopefully there will be more clues to solve this question.

In addition, the animal remains indicate sustainable hunting and fishing strategies. The analysis of cull patterns, scheduling, and hunting and fishing strategies suggests that the resources were not over exploited, and the ecosystem

was kept in balance during the occupation of Tianluoshan.

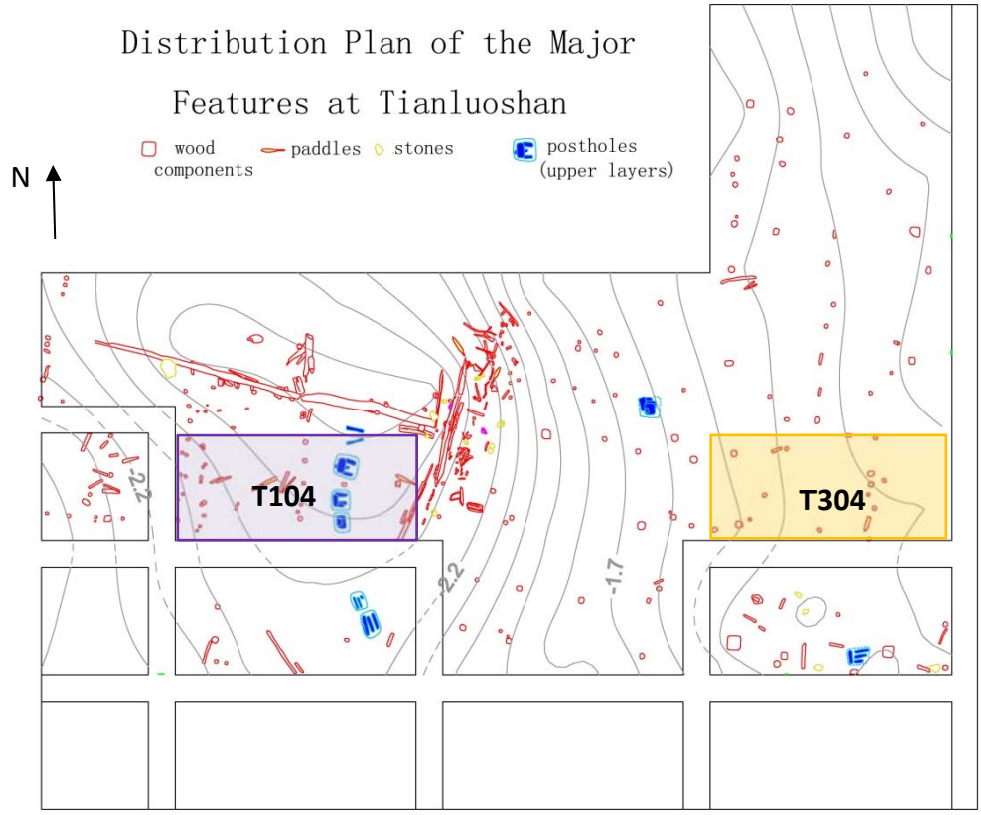


Figure 8.14 Location of trenches T104 and T304 on the site plan, containing completely different features. Map is reproduced from Sun (2011).

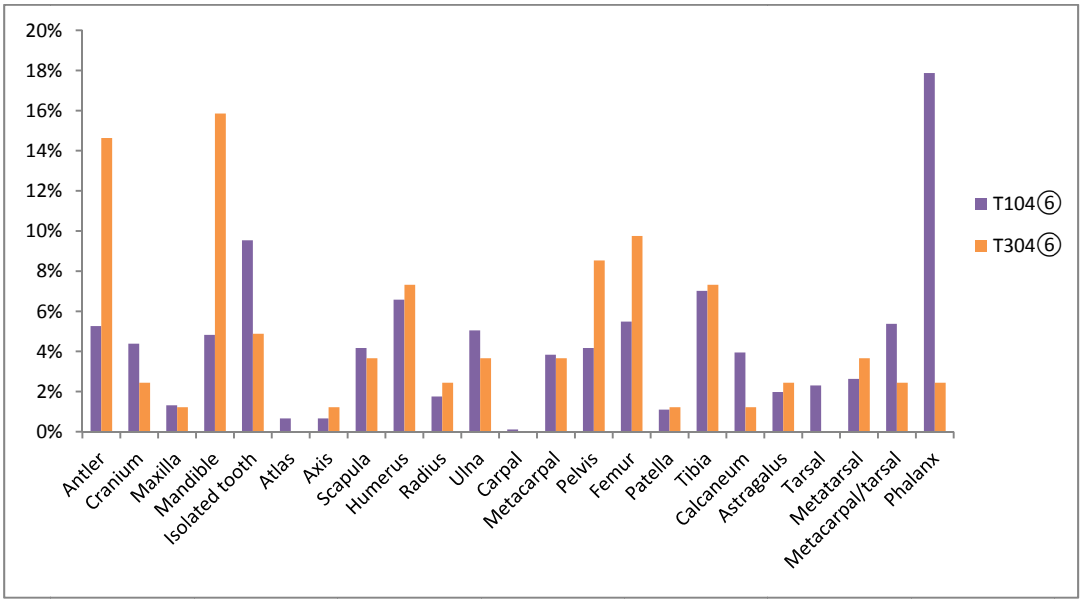


Figure 8.15 Distributional difference of cervid body part representation in trench T104 and T304.

Table 8.11 The NISP of cervid skeletal parts in layer 6 in trench T104 and T304.

	T104⑥	**T304⑥**
Antler	48	12
Cranium	40	2
Maxilla	12	1
Mandible	44	13
Isolated tooth	87	4
Atlas	6	0
Axis	6	1
Scapula	38	3
Humerus	60	6
Radius	16	2
Ulna	46	3
Carpal	1	0
Metacarpal	35	3
Pelvis	38	7
Femur	50	8
Patella	10	1
Tibia	64	6
Calcaneum	36	1
Astragalus	18	2
Tarsal	21	0
Metatarsal	24	3
Metacarpal/tarsal	49	2
Phalanx	163	2
Total	912	82

8.7 Discard: the intra-site distribution

The body part representation indicates that all skeletal parts, no matter whether fish or mammals, are present at the site (see Chapter 5 and Chapter 7). However, the animal remains are unevenly distributed across the site. A simple quantification suggests that animal remains are more densely accumulated in the west and north parts of the excavation area, basically at the waterside and outside of the pile-dwelling. In order to value the intra-site difference of animal remains distribution, two trenches, T104 and T304 from different areas of the site (Figure 8.14), are selected for further quantification. All cultural layers (3-8) of T104 have been

excavated. The excavation in T304 is currently halted at the bottom of layer 6, which the pile-dwellings belong to. Given that layer 6 is very rich in animal and plant remains, animal remains only from layer 6 are taken for distributional analysis.

As animals were hunted for different purposes (see above), only deer remains, which are in relation to meat consumption, raw materials, and hide, are used for analysis. The NISP and body part representation of the deer remains from both contexts are listed in detail in Table 8.11. Clearly the remains are accumulated more densely in T104 layer 6, nearly ten times more than those in T304 layer 6. The proportional differences of each skeletal part between two contexts are shown markedly in Figure 8.15. T104 is relatively rich in isolated teeth and foot bones including phalanges, tarsals, metacarpals and metatarsals. These lean parts tend to suggest that the waterside was the place to discard waste from animal processing. By contrast, the proportions of antlers, mandible, pelvises, and femurs are quite high in T304. These elements can be roughly classified into two groups, the meaty parts (girdle and limb bones) and the part suitable for making tools (antlers), indicating that meat consumption and tool production were possibly practiced in the living area. The differences between these two contexts reflect the functional variations between the low-lying waterlogged area and the resident area of the site.

8.8 The Neolithic subsistence economy in the Lower Yangtze River region

The Neolithic sequence and an overview on the subsistence of the cultures have been summarized in Chapter 2. In general, the entire subsistence economy was dominated by hunting, gathering, and fishing elements throughout the Neolithic; domestication only occupied a minor position in the subsistence.

There has not been enough evidence to investigate the animal subsistence of the early Neolithic in the lower Yangtze River valley. Presumably wild animals, especially the cervids and the bovids, are the major meat resource during this period. How many animal resources were exploited? Did any diet breadth revolution occur in the lower Yangtze River valley by the early Neolithic? The animal remains from those sites may provide the answers to these questions. The plant food used during this period includes various wild plants, such as acorns, Job's tear, and wild rice.

Wild resources still dominate the subsistence in the middle Neolithic, but pig domestication and rice cultivation might have emerged. However, both food resources only occupied minor position in the subsistence economy.

It is clear that the subsistence became more diverse in the late Neolithic. The entire subsistence economy was highly reliant on the wild resources, whilst rice cultivation developed throughout this period. The pig domestication possibly developed according to previous study. However, the analysis of the animal remains from Tianluoshan proposes a rather conservative opinion about the process of animal domestication. Chapter 7 presents the analyses of the pig remains from all possible perspectives and suggests they belong to wild boar. A comparison of the pig remains from the sequential sites in the Lower Yangtze River valley also tends to indicate the origin of pig domestication in this region might be later than what was proposed.

The wild resources, mainly the cervids, continued to play an important part in the subsistence economy during the epi- and the final Neolithic. The proportion of domestic pig was rather stable during the epi-Neolithic, possibly climaxed in the

Liangzhu period, and steadily dropped back thereafter (see Figure 7.31). The Bianjiashan site of the Liangzhu culture has extremely high proportions of *Sus* NISP and MNI (over 80%) in the animal assemblage. The analysis of these *Sus* remains suggests the assemblage contains remains belonging to domestic pigs. It indicates the development of pig domestication in or by the final Neolithic. However, Bianjiashan is a single example which may not reflect the subsistence conditions of the Liangzhu culture. The assumption would be more persuasive with more material from the Liangzhu Culture.

Among the wild animals, fish might have been a very important and reliable protein resource for daily consumption throughout the Neolithic. The lower Yangtze River valley has plenty of fresh water bodies of various kinds: river, brook, lake, pond, wetland, etc. There is no doubt fish and other aquatic resources (animals and plants) have been playing a very important part in the subsistence, and they still are. Yuan and colleagues proposed that fishing and hunting were the primary modes of meat acquisition in the Yangtze River valley in Neolithic (Yuan et al., 2008). Fish remains are commonly present in the archaeological animal assemblages along the Yangtze River, particularly when sieving is systematically applied (Table 1 in Yuan et al., 2008). At Zhongba, a salt production site of final Neolithic and Bronze Age in the upper Yangtze River valley, fish remains comprise a considerable majority of the animal assemblage (Flad, 2004, 2005, Flad and Yuan, 2006).

The 'rice-fish subsistence (饭稻羹鱼 Fan Dao Geng Yu)' along the Yangtze River was recorded in 'Shi Ji (Records of the Grand Historian)', the earliest historic record by Sima Qian (or known as Ssu-ma Ch'ien) more than 2,000 years ago (Sima, 1993,

P446). Judging from the intensive fish consumption and increasing rice cultivation at Tianluoshan, the 'rice-fish subsistence' at least has started in middle Neolithic. It might happen even earlier, before rice cultivation started and wild rice was exploited. During that period, wild rice only occupied minor position among the gathered wild plants; therefore, the subsistence pattern can be interpreted as the 'fish and aqua plants subsistence' instead. So far, the animal and plant remains from Kuahuqiao support this assumption. As more materials are uncovered and research proceeds, the interpretation of the subsistence economy will make significant progress, and will eventually contribute in Chinese archaeology.

8.8.1 Animal domestication in the lower Yangtze River valley

8.8.1.1 Dog

The domestic animals which have been reported in the study region include dog, pig, and water buffalo. Dog remains were widely distributed at the Neolithic sites across China. The earliest evidence of domesticated dog was from Nanzhuangtou, Xushui County, Hebei Province, dating to approximately 9,500 – 9,000 BC (Li et al., 2000, Yuan and Li, 2010). The dentition length of a dog mandible specimen from Nanzhuangtou is only 79.40 mm, whilst the same measurement of modern wolf dentition is 90 mm, indicating significant morphological difference between two sets of samples (Yuan and Li, 2010). It may also suggest that dog domestication occurred much earlier in the East Asia. The dentition length of dogs from Jiahu (7,000 – 5,000 BC) reduced further to 72.68 mm (Yuan, 2001), indicating dog mandibles shortened as domestication progressed. Plus, dogs were specially buried in cemeteries and beside of houses (Henan Province Institute of Relics and Archaeology, 1999, P130-

131), possibly indicating an intimate relationship between human and dogs.

Plenty dog remains have been uncovered from Kuahuqiao, possibly related to the hunting-gathering subsistence economy. Morphometric data suggest that the dentition lengths are shorter than the Jiahu specimens, with an average of 67 mm (Yuan and Yang, 2004). The Hemudu dog specimens do not provide comparable metric data with other sites; but the measurements indicate the Hemudu dogs are smaller than modern wolf, and are similar to the dog specimens from Zhejiang Natural History Museum. At Tianluoshan, only one measurement can be taken from a dog mandible, and its dentition length (P_1 – M_3) is 73.3 mm. Three measurements are taken on the dog mandibles from Bianjiashan (Liangzhu culture), and the mean dentition length is 66.6 mm (Zhang, 2014). The average measurement for Qianshanyang dogs is 69.0 mm (Zhang, in press).

In general, the metric data show a reduction in size of mandibles from the early Neolithic (Nanzhuangtou) to the final Neolithic stage. However, the size reduction was not very typical in the lower Yangtze River valley. Regardless of sample size, the dentition length fluctuates since middle Neolithic; dogs might be still big in size in the late and final Neolithic phase. Although without measurements, the only two dog mandibles from Jiangjiashan (Majiabang culture) lived to rather old age: their teeth started to fall, and bone absorption can be observed. It may reflect the importance dog was playing in the society.

8.8.1.2 Water buffalo

Water buffalo domestication was first proposed to start alongside rice cultivation in the lower Yangtze River. This assumption was questioned based on the DNA

analysis of multiple archaeological specimens (Liu et al., 2006, Yang et al., 2008). Therefore, the *B. Mephistopheles* was used for meat consumption rather than traction in paddy field. At Liangzhu culture sites, huge stone ploughs which were too large to draw by human beings were uncovered, but it is still unclear how those tools were used.

8.8.1.3 Pig

The topic of pig domestication in the lower Yangtze River valley is rather complicated. In general, it might be a long process, and the development varied between different areas. Domestic animals, such as wild sheep, goat, and cattle, were relatively minor hunted resources (Rowley-Conwy and Layton, 2011). Throughout the Neolithic period, pig remains are relatively low in proportion, and cervids are the major food animals throughout the Neolithic. Figure 7.31 provides the relative proportions of the main food animals: bovine, cervid, *Sus*, and carnivore. The proportion of pig remains stayed around 30% of the total NISP in the animal assemblage. As the animal remains were mostly collected by hand-picking, the actual proportion may be lower if sieving were applied, possibly similar to that at Tianluoshan. The proportions of small game, such as muntjac, water deer, rabbit, and tortoise, may increase significantly.

Confirmed domesticated pig can be identified at Jiangjiashan (Majiabang culture), judging from the small size (lower M_3), increasing frequency of LEH, and more juveniles in the population (Zhang, 2009, and Chapter 7). Meanwhile, wild boars were still hunted, resulting in a wide range of the lower M_3 length (Figure 7.8). Domestication developed greatly in the Liangzhu period. The proportion of pig

remains in the Bianjiashan animal assemblage is more than 90%. Analysis of morphometric, culling, and LEH indicates the further development of pig domestication. It might be related to the cultural prosperity of the Liangzhu culture. As the culture declined in the later period of the final Neolithic phase, the subsistence was again mainly supported by deer hunting, and the proportions of pig decreased greatly.

In general, pig domestication is the most complicated question of all domestic animals (Rowley-Conwy et al., 2012). Cross breeding between wild boar and domesticated pig occurred regularly, and it only has made this question more complicated. As we have not known how the domesticated pigs were kept at the Neolithic sites in the lower Yangtze River valley, we can only assume that it might occurred, and might have made the identification difficult.

Figure 8.16 Pig mandible from Bianjiashan, Liangzhu culture.

Cultural factors influence the exploitation of pigs as well. For example, the Liangzhu culture had a preference for artefacts made from *Sus* canines. In order to remove the canines completely, a hole was first punched on the lateral side of the mandible at the canine root to loosen it (Figure 8.16). This cultural feature may influence the *Sus* assemblage in the following way: 1) the importance of wild boar hunting in the animal subsistence; 2) male pigs tend be reared to older age to obtain fully grown canines; 3) interbreed with the wild boars might be encouraged. Reflection on the pig remains, the pigs were large in size (Figure 7.8), and many of the male pigs managed to survive until adult.

Are the domestic pigs from the Majiabang culture the earliest in the lower Yangtze River valley? When did pig domestication originate? The current point of view suggests pig had been domesticated at least since the Kuahuqiao culture, mainly based on dentition crowding on two specimens (Yuan and Yang, 2004). The lines of evidence are not strong enough to support such a conclusion. Therefore, the fifth millennium, which approximately parallels the Hemudu period, might be the key phase for investigating the origin of pig domestication.

Table 8.12 Bone collagen $\delta^{13}C$ and $\delta^{15}N$ values (‰) of pig, human, and deer from Tianluoshan. Data are summarized from Minagawa et al (2011).

Species	**Stage**	**No. of sample**	**Mean $\delta^{13}C$**	**Min $\delta^{13}C$**	**Max $\delta^{13}C$**	**Median $\delta^{13}C$**	**Mean $\delta^{15}N$**	**Min $\delta^{15}N$**	**Max $\delta^{15}N$**	**Median $\delta^{15}N$**
Pig	1	4	-20.78	-22	-19.9	-20.6	5.78	4.9	6.4	5.9
Pig	2	12	-21.08	-21.9	-20.2	-20.9	5.59	4.1	8.3	5.4
pig	3	10	-21.13	-22.7	-20	-20.95	5.48	4.3	6.7	5.5
Human	1	1	-20.3				10			
Human	2	7	-20.6	-21.9	-20.2	-20.4	8.66	8	10.4	8.1
Human	3	2	-20.9	-20.9	-20.9		8.3	8.3	8.3	
deer	1-3	9	-22.14	-23.4	-21	-22	5.33	4.6	6.6	5.2

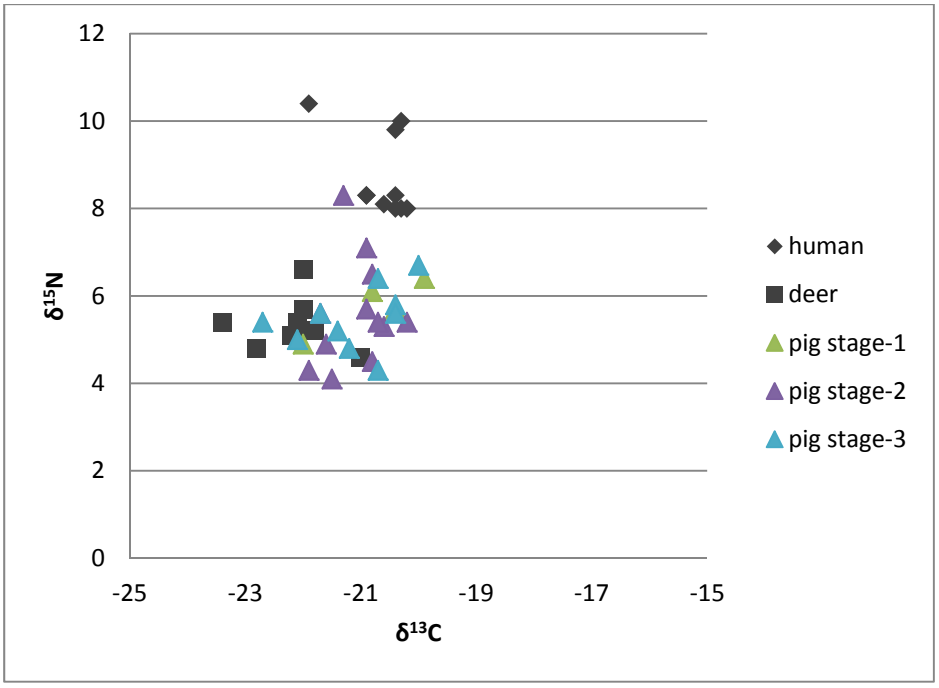


Figure 8.17 $\delta^{13}C$ and $\delta^{15}N$ values for faunal and human bone collagen from Tianluoshan. The scatterplot is reproduced from the data by Minagawa et al. (2011).

In Chapter 7, pig remains from Tianluoshan have been thoroughly analysed, and have come to the conclusion that they belong to the local wild boars. Minagawa and colleagues (2011) suggested that a few pig specimens had higher $\delta^{15}N$ values than the others, close to human, indicating the emergence of pig husbandry. All data for this stable isotope analysis were included in this paper, so I summarized these data (Appendix 7), had them sorted, and plotted in Figure 8.15. Based on Minagawa and colleagues' research, the values of pigs from Stage 1, 2, and 3 were plotted separately, in order to view the change through time if there was any. The mean values of each stage were calculated as well (Table 8.12). Figure 8.17 and Table 8.12 show that the $\delta^{13}C$ values of human, pig, and deer from Tianluoshan fall into the range of C_3 plants, indicating they all fed on C_3 plants. The values of pigs overlap with both deer and human, and this result may be related to the complicated diet of pig and the sample size in this study. The $\delta^{15}N$ results show that the values of pig are

overlaps with those of deer, but are mostly separated from those of human. Only one sample from Stage 2, which has the largest sample size of animal remains, falls into the range of human $\delta^{15}N$.

There have been several successful cases in Chinese archaeology using stable isotope analysis of carbin and nitrogen to identify domesticated pigs from wild boars. The examples are mostly in the Neolithic North China where domesticated millet (C_4 plant) gradually replaced gathered C_3 plants. Domesticated pigs show similarity with human in both $\delta^{13}C$ and $\delta^{15}N$ values, and are different from wild boar specimens (Guan et al., 2007, Hu et al., 2008). In the lower Yangtze basin, domesticated rice and wild resources consist of C_3 plants, so human and wild animals share similar $\delta^{13}C$ values like shown in Figure 8.17; but there may be difference between $\delta^{15}N$ values. Therefore, the single speciemen in Stage 2 may have shown tendency of pig feeding and even domestication.

Even if pigs (wild boars) were fed at Tianluoshan, it was probably used as a backup food resource to be consumed during the lean seasons. Pig feeding was only a supplementary strategy, and we have not got evidence to know whether pigs were bred at site. As the pig remains do not show any morphological change through time, we can assume that pigs were not bred at site yet. However, pig feeding infers 'progress' from hunting, and it might lead to pig domestication soon after the Hemudu period. The results from Tianluoshan fit in the chronological sequence of pig domestication in the lower Yangtze River valley.

Rice domestication in the lower Yangtze River valley displays a similar trend. Non-shattering spikelet bases have been found at Kuahuqiao, indicating primitive rice cultivation in the middle Neolithic. Rice cultivation further developed in the following Hemudu period. The proportions of domesticated rice increased gradually over the

Hemudu period from 27% to 39%; over the same period, rice remains increased from 8% to 24% of all plant remains, indicating growing consumption of rice comparing to wild gathered foods (Fuller et al., 2009). The proportion of domesticated rice increased greatly from 51% in the early phase to about 95% in the late phase of Majibang culture in the Taihu Lake region, although wild gathered aquatic plants took large percentage of all plant remains (Gao, 2012, Zheng et al., 2007). The appearance of paddy field might have accelerated the process of rice domestication; therefore, the proportion kept high over the following Songze and Liangzhu period in the Taihu Lake region.

Furthermore, the stable isotope analysis indicates little marine resource was used, unlike what was proposed by (Jiao et al., 2011). Wooden paddles have been uncovered from Tianluoshan, but they are more likely to be used in the inland rivers and lakes rather than for marine fishing. However, the sites of Hemudu culture are distributed in an elongated area extending from the Ningshao Plain to the Zhoushan archipelago in the East China Sea (Figure 2.1). Marine resources might have played an important part in the subsistence economy at the sites close to the East China Sea, showing diversity within the Hemudu culture. What was the subsistence economy like at those sites? How were fish used? Did rice domestication occur there? These can be the research questions for interpreting the Hemudu culture in the near future.

8.8.2 Development patterns of subsistence in China

Comparing to the later cultures in the lower Yangtze River region, the Hemudu culture relied more on the diverse wild foods. Rice and pig, which became more and

more important since late Neolithic phase, were only supplementary food resources during the Hemudu period. The major food resources, i.e. the wild plants and animals, were gathered and hunted from the diverse environments around the site. Those catchments could be reached within a few hours' walking.

The subsistence evolution in the lower Yangtze River valley displayed a distinctive pattern, different from that in the Yellow River valley. The Yellow River and the Yangtze River regions are well known as the cradles of Chinese cultures and the independent yet connected centres for the origin of agriculture in China. As presented in this thesis, the Yangtze River region is the origin of domesticated rice, and possibly another centre for pig domestication. The domestication process of both species lasted for at least a thousand years. The Yellow River region is the origin for domesticated foxtail millet (*Setaria italica*), common millet (*Panicum miliaceum*), soybean (*Glycine max*), and pig (Larson et al., 2010, Lee et al., 2011, Lu et al., 2009a, Zhao, 2011, Crawford, 2009). The origin of agriculture in this region can be dated back to about 10,000 years ago (Lu et al., 2009a), and this tradition has been passed along until now.

Qin (2012) thoroughly reviewed the process of agriculture in the Yangtze River and the Yellow River regions, and discussed the different agriculture patterns in the Yangtze River and the Yellow River regions. In the Yellow River valley, the domestication of two millet species started after the sedentary occurred, and was achieved rather quickly. Millets soon replaced wild gathered plants and became the major food resources for subsistence. In contrast, rice domestication was delayed in the Yangtze River valley. Rice cultivation existed alongside wild food gathering as a

supplementary resource exploitation strategy for several millennia before domesticated rice finally replaced wild resources to become the main plant food.

Similarly, the animal subsistence displays different development paths in the Yellow River region and the Yangtze River region. Pig domestication appeared relatively earlier in the Yellow River region. According to Yuan and Flad (2002), the earliest domesticated pig so far was from Cishan site in Hebei Province, dating back to approximately 8,100 BC, same time as Kuahuqiao in the Yangtze River region. Complete pig skeletons of 1 year old were buried in pits, underneath large amount of charred millets, which were recently identified to be common millets rather than foxtail millets as expected (Lu et al., 2009b, Lu et al., 2009a, Mayer, 1998). Since then, domesticated pigs played a more and more important part in the subsistence. In the lower Yangtze River valley, Pig domestication might start at the beginning of the fourth millennium BC, and temperate feeding of pigs (possibly wild) could occur in the fifth millennium BC (see above). The subsistence economy features in the intensive exploitation of wild animals (including mammals, reptiles, and fish) throughout the Neolithic.

Catchment analysis reveals difference in resource exploitation range of sites both regions. Tianluoshan from the lower Yangze River region and Yuanqiao from the Yellow River valley are used for comparison (Qin et al., 2010). At Tianluoshan, the resources (mostly plants) are mainly from the wetlands and shrubs within 2-4 hours walking from the site; some fruits and wood may be gathered from the mountains 10 km away, at least 12 hours walking. Zooarchaeological analysis in this thesis supports this result. In contrast, at Yuanqiao, domestic common millet, foxtail millet, and a

small proportion of rice and wild soybean are the main plant resources, and they can all be achieved in a small area less than one hour walking. Animal resources include catfish, shellfish, bird, and small deer which can be gathered from this small area. Yuanqiao is located by a stream in a narrow valley, where the diverse environments and wild resources can be found in a small range, approximately within 2-3 hours walking. Nevertheless, the Yuanqiao people chose to live on the foods closer to the site, indicating it is likely due to subsistence strategy rather than the richness or scarcity of wild resources. Tianluoshan and Yuanqiao each represent a consistent subsistence model of those two centres for Neolithic cultures in China. The rich and diverse wild resources in the lower Yangtze, especially fish, provide sufficient conditions for the subsistence model.

8.8.3 The rice-fish eco-subsistence

The Yangtze River region has a very long history of consuming rice and fish. The use of wild rice in the lower Yangtze can be dated back to 10,000 – 8,500 BP, and it became more and more important in the subsistence ever since (Qin, 2012). Fish remains have been commonly uncovered from this region, perhaps usually in large amount (Yuan and Yang, 2004, Zhejiang Provincial Institute of Cultural Relics and Archaeology, 2003, Nakajima et al., 2010a). Given the importance of both resources and their relationship (Chapter 6), the term 'rice-fish eco-subsistence' is raised as a component of the subsistence economy. This term aims to describe a subsistence system within an ecosystem with various connected elements. It may help to understand the subsistence logically.

On the basis of paddy field ecosystem, the rice-fish eco-subsistence may only

contain a few fish species adaptive to the environment where rice grows. In the case of Tianluoshan, the fish include two cyprinids, snakehead, and catfish which can survive the anaerobic waters in the wetlands. Therefore, for different rice, e.g. deep water rice, the fish species in the eco-subsistence may vary accordingly. Nevertheless, based on archaeological, ethnographic, and agronomic records, cyprinids, snakehead, and catfish are among the most common fish adaptive to the rice growing environment. Consequently, these fish are intentionally chosen for the rice-fish farming several millennia later.

Where there is water, there are fish. Fish in the wide wetlands may voluntarily migrate to the rice field for feeding and sheltering, especially during the primitive rice cultivation when the rice growing field is open to the wetland water body. Fish and rice benefits each other in the ecosystem. Fish contributes nutrient to the rice field through the excretion of faeces and decomposition of dead fish. When fish swim and disturb the soil-water interface – as happens frequently as most rice field fish prefer turbid water – nutrients such as nitrogen are released from soil. Fish are also effective pest control and weed control for rice. Meanwhile, rice field provides food, shelter, and spawning ground for fish. Therefore, rice field has been an important fishing ground in many places of the world. Fishing in open rice (growing) field can be seen as a type of wetland fishing.

Paddy field fishing involves several strategies (Chapter 6), and some of them may leave a trace in fish remains. The body length distribution in Figure 3.4 (a) refers to paddy field fishing, and Figure 3.4 (b) refers to open environment fishing. When the rice field is drained before harvest, fish left in the rice field – mostly newly hatched in

the summer – are captured, creating an extra peak on the distribution. Patched paddy fields have been uncovered at Majiabang culture sites and Songze culture sites (Chapter 2). The very recent excavation at the site of Majiabang has exposed large amount of fish bones (personal communication with Mr. Rui Guoyao, director of the Majiabang excavation project); common carp and snakehead can been identified. As different water management is applied in the rice cultivation at Tianluoshan and Majiabang, a comparative study of the fish remains from these two sites may reveal whether rice cultivation influenced fishing and how.

In addition, the rice-fish eco-subsistence is usually accompanied by wild aquatic plants gathering, such as water chestnut and foxnut (Qin, 2012). These wild resources gradually declined in the final Neolithic phase as rice agriculture grows. The lower Yangtze was well known as 'a fertile land of fish and rice (鱼米之乡 Yu Mi Zhi Xiang) '. Historical records indicate that people in the middle and lower Yangtze River still relied a lot on rice, fish, and other wild resources in the Bronze Age. According to Sima Qian's recording in 'Shi Ji', people mainly live on rice and fish soups, as well as all gathered fruit, berries, and shellfish. "Since the land is so rich in edible products, there is no fear of famine, and therefore the people are content to live along from day to day." Meanwhile in the lower Yellow River region, "land is scarce and the population dense, and the area often suffers from floods and drought; the people therefore take good care to lay away stores of food; (in the kingdoms) agriculture is favoured and the peasants are held in esteem." (Sima, 1993, P446). Thousands years of rice-fish eco-subsistence might finally promote the emergence of rice-fish farming.

Rice-fish farming has been practiced in China for nearly 2,000 years (Li, 1992, Cai et al., 1995). An intact rice-field model made of red clay was unearthed in an Eastern Han Dynasty (25-220 AD) tomb in Shanxi Province. The model also contained 18 pieces of pottery miniatures of common aquatic plants and animals, such as lotus flowers, lotus leaves, lotus seed, water chestnuts, duck weeds, soft-shelled tortoises, grass carp (*Ctenopharyngodon idellus*), and goldfish (*Carassius auratus*) (Guo, 1985). There are more records of rice-fish farming along the Yangtze River after the Han Dynasty, such as in the Three Kingdoms period, Tang dynasty, and Song dynasty. The fish cultured in rice field include both wild and cultivated species. Currently in China, common carp, tilapia, grass carp, catfish, and loach are commonly cultured in the paddy fields (Li, 1992). Although not cultured, different species of snakeheads can be fished in rice fields, e.g. northern snakehead in most part of China, blotched snakehead in the Pearl River region, and striped snakehead in Southeast Asia.

Common carp (*Cyprinus carpio*) has been cultured as a pond fish for over 2,000 years. Chinese scholar suggested that it started at the end of the Shang Dynasty (1401 – 1154 BC), and *C. carpio* was the only cultured species until the Tang Dynasty (618 - 907 AD) (Li, 1992). Therefore, in Han Dynasty, common carp might be deliberately stocked in paddy field, whist the other fish and soft-shelled tortoises were introduced into the field through irrigation. Eating common carp (‘鲤’ pronouncing ‘li’) was tabooed in Tang Dynasty as it sounded the same as the surname of the emperor family (‘李’ pronouncing ‘li’). Thus, four carp species were cultured as the food fish, including black carp (*Mylopharyngodon piceus*), grass carp (*Ctenopharyngodon idellus*), silver carp (*Hypophthalmichthys molitrix*), and bighead

carp (*Aristichthys nobilis*). The fish culture techniques were further developed in the Song Dynasty (960 – 1279 AD). However, these four cultured fish were not truly domesticated. Unlike common carp and crucian carp, they can only spawn in deep and running waters in the rivers rather than sluggish waters. The technique of culturing fish uses their habitat of migration, to collect the hatchlings from the rivers and feed them in ponds (personal communication with Professor Zhang E). The earliest domesticated fish is the goldfish (*Carassius auratus*), which has been known since 960 AD as an ornamental animal in the garden pools (Balon, 2004).

To sum up, in the lower Yangtze, various wild resources have played an important part in the subsistence since Neolithic. In nowadays, wild gathered foods are still treated as delicacies in this region. Coincidentally, the early records of rice-fish farming are usually about the upper and middle Yangtze rather than the lower Yangtze. The rich natural resources and a tradition of wild food consumption may be the holdbacks for rice-fish farming.

8.9 Conclusion

This chapter aims to interpret the subsistence of Tianluoshan as an integrated system. Each element of the subsistence is first discussed separately, and then integrated to get a broad view. The discussion includes temporal dimension and spatial dimension.

The THI method is introduced to investigate the spatial dimension of resource exploitation. It is first employed to analyse the ecological diversity of mammalian resources, and then to measure the hunting intensity of each habitat type by integrating MNI into the THI values. The result suggests shrubs were frequently

exploited for mammal hunting. Furthermore, the exploitation of fish and plants is evaluated with the same method, so that the results can be compared with that of mammal remains. The results indicate a mosaic distribution of the habitat use. Like proposed in Chapter 5 and 6, most fishing occurred in the wetlands close to the settlement. Wetlands were also the main source for most plant food, except that in the very early phase of the Hemudu period woods were intensively exploited for acorns. Timbers were obtained from the forests in higher hills and mountains.

This thesis presents a novel approach, to integrate the zooarchaeological and archaeobotanical data. Since there are great differences between the quantifying mammal, fish, and plant remains, the THI method transfers the number of species into an index value, so that both datasets can be viewed and compared at the same level. The Tianluoshan project has proved the capability of THI for interpreting the spatial dimensions of exploiting various resources.

The discussion of temporal dimensions is based on individual analysis of different resources. A calendar is created accordingly, showing the scheduling of food exploitation. In general, the Tianluoshan calendar is rather efficient and sustainable. First, the concentrated exploitations were arranged at different time of year based on the attributes of resources and labour management. Since the harvest time of the highly seasonal foods (i.e. nuts and fruits) is fixed, the exploitation time of the other resources which are available for most of the year is scheduled to adapt the seasonal foods. The Jomon calendar displays the same pattern. The seasonal foods in Jomon period include nuts, fruits, and marine fish; pottery making can only occur during the dry seasons. Therefore, the exploitation of less seasonal resources can only be

arranged at the spare time of year. Second, the analysis of hunting strategies suggests the targets and hunting time were chosen on purpose, so that the animals would not be overhunted. In the Tianluoshan assemblage, the animal species, relative proportions, and the age structures of the main food animals barely changed throughout the fifth millennium, indicating sustainable subsistence strategies at Tianluoshan.

Tianluoshan provides large amount of waterlogged remains for the research of subsistence economy. The most important finding is probably domesticated rice which gradually increased over the Hemudu period. It might indicate the beginning people started to manage the rice-fish eco-subsistence. There has been a long history of consuming fish, rice, and other wetland resources in the lower Yangtze. Catchment analysis of Tianluoshan has inferred the increasing importance of wetlands in the subsistence. From the Majiabang culture, the low-lying Taihu Lake plain became the centre of Neolithic cultures, indicating wetlands (including paddy field, the artificial wetlands) might be the main area for food resources. Fish has been an important byproduct of rice cultivation; in some areas in the upper Yangtze fish are cultured as the second crop in the rice field.

The subsistence pattern of the lower Yangtze shows distinctive differences with the other agriculture origin, the Yellow River region in North China, over the Neolithic, and probably the long history thereafter. A significant feature of the Yangtze River region is the intensive exploitation of fish and other wild food resources, which may have led to delayed domestication of animals and plants.

Chapter 9 Conclusions and proposals for future research

This thesis aims to interpret the subsistence economy of the late Neolithic in the lower Yangtze River region, and to assess the dynamic relationships between human and various animals, by studying the faunal remains from Tianluoshan.

In this chapter, I present the conclusions drawn from this thesis, assess the contributions this research might make to Chinese zooarchaeology, and discuss my plans for future work.

9.1 Conclusions to be drawn from the research

9.1.1 Interpretation of fishing subsistence

Data analysis and interpretations of fish remains in Chapters 5 and 6 allowed the following conclusions to be drawn.

Firstly, the NISP and MNI of fish remains are abandunt, showing intensive use of these resources. Only a limited number of fish species are included in the assemblage; three freshwater fish -- snakehead, crucian carp, and common carp – take the most proportions of the fish assemblage, indicating selective fishing at Tianluoshan.

Secondly, a brief ecological analysis of the freshwater fish suggests there might be a vast area of vegetated brackish water bodies close to the site, and it was probably the main fishing ground. This conclusion tallies with the paleo-environmental analysis in the Tianluoshan integrated research project.

Thirdly, the seasonality analysis of three predominant fish reveals two features of the fishing practice. On one hand, fishing was undertaken throughout the year, indicating fish was probably a reliable food resource for subsistence. On the other hand, intensive fishing events, each targeting a single fish species, occurred annually at a fixed time of year. The fishing seasons were determined according to the life cycles of different fish, indicating Tianluoshan people's rich knowledge about fish and possibly the management of labour.

In Chapter 6, the fishing strategies and techniques are discussed from various possibly perspectives, by analysing the environmental issues, ethnographic records, archaeological materials, different fishing methods of the world, and most importantly, fish remains. Although I cannot tell what specific gears were used for fishing, they can be narrowed down to a few groups. Fishing methods selective by fish size were probably employed at Tianluoshan, such as trapping, casting, and scooping with gear made of organic materials. Multifuntional tools which are not commonly considered to be related to fishing might be used to catch fish as well.

9.1.2 Interpreting the subsistence economy of Hemudu culture

This research reveals a complex subsistence economy featuring sustainable and well organized hunting, fishing, gathering, and increasing rice cultivation over the Hemudu period.

First of all, the Hemudu culture was heavily reliant on wild resources, including acorns, wild aquatic plants, fruits, wetland fish, several deer species, wild boar, water buffalo, etc. There were specialized hunter-gatherer-fishers. Cultivated rice, on the other hand, was a supplementary food resource.

Secondly, resources exploitation mostly occurred in the environment close to the settlement, including the wetlands, dry grassland, and shrubs within a few hours' walking range. Resources were quite concentrated in these environments, especially in wetlands, where the stable foods i.e. fish, water chestnuts, foxnuts, and rice were gathered. Shrub forests, on the other hand, were the major hunting ground.

Thirdly, an integrated scheduling of the plant and animal resources indicates a well-planned calendar for resources exploitation considering the life cycles of the target resources and labour management, to make the most profit out of them.

Fourth, the hunting strategies of sika deer, muntjac, and boar indicate the wild animal resources were exploited in a sustainable way, never exceeding the carrying capacity of the environment. Rich resources and sustainable exploitation are possibly the reasons for delayed domestication.

Fifth, agriculture might have emerged in the Hemudu period. Rice domestication had started and gradually became more and more important over the Hemudu period. In contrast, pig domestication had not begun judging from thorough analysis of pig remains, but stable isotope analysis suggests occasional feeding might have occurred. Therefore, the Hemudu culture is crucial for studying the process of pig domestication in the lower Yangtze.

At last, fishing and rice cultivation might be related. The relative proportions of fish changed along with the development of rice cultivation. This assumption need to be examined with more archaeological materials in the future.

9.1.3 Subsistence change in the Neolithic lower Yangtze

The subsistence economy of Hemudu culture is placed back in the Neolithic culture sequence of the lower Yangtze to investigate the subsistence change in broader context.

For most time of the Neolithic period, generally from early Neolithic to late Neolithic phase, the subsistence economy was dominated by hunting, gathering, and fishing elements, and domestication only occupied a minor position in the subsistence. This conclusion is drawn based on the research of large mammal remains (larger than dog-size) and plant remains. Morphological studies of pig remains from Tianluoshan suggest they belonged to wild boar rather than domesticated pigs. The relative proportions of the major food animals reveal a consistent deer and wild boar hunting pattern over the Neolithic period. Based on the research of the Tianluoshan faunal remains, the proportions of deer from the Neolithic sites, featuring the small deer such as muntjac, water deer, and tufted deer, should have been higher as long as sieving was applied during excavation. Wild nuts, fruits, and gathered aquatic plants were the major plant resources during this long time. In contrast, domesticated rice was still supplementary in the Hemudu period.

The fifth and fourth millennia BC may be the crucial period to investigate the origin of pig domestication. This is also the period when rice domestication developed at an accelerated speed. The growing rice cultivation might have provided conditions for pig husbandry. Thereafter, pig domestication peaked in the Liangzhu period. The faunal assemblage at Bianjiashan mainly consist of pig remains, the wild animals are few.

The use of fish resources in the lower Yangtze is barely discussed, although its importance in the subsistence economy has been realized. The case study of the fish remains from Tianluoshan has proved the importance of fish in subsistence, and revealed the relationship between fishing the use of aquatic plants, especially rice. Therefore, we may propose intensive fish consumption continued along with the development of rice cultivation, and was not replaced by animal domestication. According to ethnographic records and previous research on fishing in Yayoi period in Japan, the fishing strategies might have changed as paddy fields developed, and it can be indicated by the relative proportions of fish, fish size, fishing seasons, etc. Therefore, fish remains are indicators for rice agriculture.

9.2 Assessing the methodologies

Standard zooarchaeological methods have been adopted in this research to assess the status of pig and the hunting and fishing strategies of Hemudu culture. The interesting part of the status of pig is the slight conflict between the results of standard zooarchaeological study and stable isotope analysis, indicating a specific phase in the delayed domestication process in the lower Yangtze River region. The conclusions of fishing strategies are basically drawn from the analysis of fish vertebrae, basioccipitals, and teeth (for cyprinids). Vertebrae are usually not preferred by the ichthy-zooarchaeologists, but the case study of Tianluoshan suggests vertebrae provides much information for identifying fish species, size reconstruction, and investigating fishing strategies, especially for assemblages with not too many fish species like Tianluoshan.

The life histories of the target animals are studied in this research, in order to

gain a realistic understanding of the subsistence. Through this method, we may view the animals from the hunters'/fishers' eyes, and easily understand why, when, where, and how were these animals captured. A subsistence calendar is generated based on standard zooarchaeological analysis and the life cycles of the prey. Ethnographic records provide lines of evidence to interpret the subsistence strategies. In addition, an ecological index (THI) is introduced to examine the diversity of the animals, and further modified to evaluate the intensity of resource exploitation in different environments. By placing the subsistence activities back in the environment and the ecosystem, we can view the subsistence from different dimensions, spatial, temporal, and dynamic.

9.3 Contributions and proposals for future research

In this thesis, I hoped to solve the questions which have been haunting me since the pilot study of the animal remains from Tianluoshan. Now I have found the answers to most of the questions, except why did the Tianluoshan people hunt monkeys. I have challenged the current opinion about the development of pig domestication and animal subsistence in the lower Yangtze River region of Neolithic period. I have proposed in this thesis that pig domesticated was a delayed process and it might originate millennia later than expected. I have analysed the hunting strategies of sika deer and muntjac which have been barely discussed in Chinese zooarchaeology. The thorough analysis of fish remains in this thesis contributes a pioneer study, and provides comparable dataset to the zooarhcaeological studies in the lower Yangtze. Systematic research of the plant remains has been undertaken in the past few years. Qin proposed that the exploitation range of animals and the rice-

fish subsistence required further investigation (Qin et al., 2010, Qin, 2012). This research happened to answer her proposals and fill the gap of subsistence study of the Hemudu culture.

This research investigates the fish and mammal remains from Tianluoshan, but the birds, reptiles, and possibly amphibians have not been studied. These animals are important for understanding the diet breadth and subsistence strategies of the Hemudu culture. From the conclusions in this thesis, we may propose most of these unstudied animals are from wetlands, but it need to be examined in the next step of research. The exploitation of the small animals will be discussed as well. Another question requiring further investigation is the animal processing at Tianluoshan. The body part analysis in Chapter 7 indicates processing was probably undertaken at site, and discarded *in situ*.

This research has provided a comparable case for the study of Neolithic subsistence in the lower Yangtze River region. In the past few years, sieving has been introduced to many sites conducted by the Zhejiang Provincial Institute of Archaeology, and fish remains have been commonly collected. In the near future, I would like to study the animal remains from Majiabang. Majiabang is located on the Lake Taihu plain, representing the late phase of Majiabang culture, slightly later than the date of Tianluoshan. Large amount of animal remains, including mammals and fish, have been retrieved from Majiabang. Archaeobotanical research has been undertaken recently. Presumably, Majiabang may provide important lines of evidence to investigate the development of subsistence in the lower Yangtze.

Appendix 1 Measurement and wear data of pigs from Tianluoshan.

Stage	Trench	M1		M2		M3		Tooth wear stage				
		L	W	L	W	L	W	dm3	P4	M1	M2	M3
1	T104								c			
1	T103	13.52	11.1						b	f		
1	T005	15.71	11.28	19.71	14.47	36.21	16.15		c	f	e	a
1	T103				14.52	40.94	16.26				e	a
1	T103	14.8	10.99	20.26	14.6	40.62	16.11			f	e	a
1	T203								d			
1	T003	20.21	13.93							a		
2	T104	15.58	11.14					d		a		
2	T104								a			
2	T104	16.19	11.53						b	e		
2	T104	18.21	11.08									
2	T104								d			
2	T003	14.36	11.52	20.45	15.69						d	
2	T301		13.63	21.11	16.29	45.51	19.68					
2	T301		12.29	21.82	15.87		17.89		e	g	d	c
2	T301			20.54	15.18	37.72	15.88				f	d
2	T301					43.71						c
2	T301					37.48	18.97					a
2	T305	15.9	13.15									
2	T304			20.78	15.83	47.22	18.76				m	j
2	T303								g			
2	T306	16.58	11.57							e		
2	T104					38.72	18.74					d
2	T105	14.64	11.02	18.3	13.65					c	a	
2	T105			18.3	13.25						a	
2	T105			20.63							d	
2	T105			18.55	13.5							
2	T304			21.25	15.37	41	17.5				e	b
2	T106								a			
2	T006	15.07	11.39							e		
2	T005			21.56	15.94						g	
2	T106							b				
3	T103					42.09	17.13					
3	T106			19.3	15	36.28	15.75				f	
3	T106	21.16	15.16							k		
3	T104			16.4	15.8	21.6				约 d		
3	T104											c
3	T103	16.02	12.64	19.61	15.18	36.27	16.47		d	m	f	d
3	T105											a
3	T105	16.62	11.82							c		

3	T105	15.99	13.26	20.15	16.55	38.9	19.07		b	f	e	a
3	T004			21.56	17.86						a	
3	T005							c				
3	T105	15.85	11.49							c		

Appendix 2 Measurement data for the length of lower third molar (M_3) of pigs from archaeological sites across China. (Only the maximum, minimum and mean value are shown here.)

Site	Region	Date (B.P.)	MNI	Max	Min	Mean
Kuahuqiao	Lower Yangtze River	8,200–7,000	13	42.37	34.29	38.54
Tianluoshan	Lower Yangtze River	7,000-6,000	14	47.22	36.21	40.19
Weidun	Lower Yangtze River	Appr. 6,000	11	47.5	36.5	40.7
Jiangjiashan	Lower Yangtze River	5,900-5,700	30	48.1	32.5	36.44
Bianjiashan	Lower Yangtze River	4,800-4,300	28	42.36	28.42	36.18
Qianshanyang	Lower Yangtze River	4,400-4,000	3	37.12	35.79	36.31
Maqiao	Lower Yangtze River	Appro. 3,000	9	42.94	36.64	40.15

Appendix 3 Body part representation of Sika deer from Tianluoshan

	Stage 1			Stage 2			Stage 3		
	MNE	**Expected**	**%**	**MNE**	**Expected**	**%**	**MNE**	**Expected**	**%**
Phalanx 3	2	104	1.9	40	440	9.1	6	200	3.0
Phalanx 2	14	104	13.5	66	440	15.0	15	200	7.5
Phalanx 1	14	104	13.5	61	440	13.9	26	200	13.0
Metatarsal, D	3	26	11.5	23	110	20.9	9	50	18.0
Metatarsal, P	4	26	15.4	31	110	28.2	8	50	16.0
Astragalus	6	26	23.1	45	110	40.9	22	50	44.0
Calcaneum	14	26	53.8	61	110	55.5	41	50	82.0
Tibia, D	14	26	53.8	62	110	56.4	29	50	58.0
Tibia, P	14	26	53.8	70	110	63.6	27	50	54.0
Patella	1	26	3.8	17	110	15.5	3	50	6.0
Femur, D	17	26	65.4	73	110	66.4	26	50	52.0
Femur, P	19	26	73.1	70	110	63.6	23	50	46.0
Pelvis	16	26	61.5	78	110	70.9	17	50	34.0
metacarpal, D	2	26	7.7	28	110	25.5	8	50	16.0
Metacarpal, P	5	26	19.2	35	110	31.8	17	50	34.0
Ulna, D	0	26	0.0	4	110	3.6	1	50	2.0
Ulna, P	11	26	42.3	61	110	55.5	24	50	48.0
Radius, D	12	26	46.2	63	110	57.3	22	50	44.0
Radius, P	8	26	30.8	50	110	45.5	28	50	56.0
Humerus, D	26	26	100.0	109	110	99.1	50	50	100.0
Humerus, P	7	26	26.9	44	110	40.0	9	50	18.0
Scapula	12	26	46.2	78	110	70.9	42	50	84.0
Axis	4	13	30.8	24	55	43.6	6	25	24.0
Atlas	5	13	38.5	25	55	45.5	4	25	16.0
Mandible	16	26	61.5	78	110	70.9	23	50	46.0
Maxilla	3	26	11.5	6	110	5.5	3	50	6.0
Skull	3	13	23.1	19	55	34.5	6	25	24.0

Appendix 4 Body part representation of water buffalo from Tianluoshan.

	MNE	Exp.	%
Phalanx 3	17	72	23.6
Phalanx 2	27	72	37.5
Phalanx 1	23	72	31.9
Metatarsal, D	3	18	16.7
Metatarsal, P	5	18	27.8
Astragalus	7	18	38.9
Calcaneum	7	18	38.9
Tibia, D	11	18	61.1
Tibia, P	12	18	66.7
Patella	1	18	5.6
Femur, D	12	18	66.7
Femur, P	3	18	16.7
Pelvis	5	18	27.8
metacarpal, D	7	18	38.9
Metacarpal, P	6	18	33.3
Ulna, D	0	18	0
Ulna, P	14	18	77.8
Radius, D	14	18	77.8
Radius, P	11	18	61.1
Humerus, D	11	18	61.1
Humerus, P	5	18	27.8
Scapula	1	18	5.6
Axis	0	9	0
Atlas	4	9	44.4
Mandible	5	18	27.8
Maxilla	1	18	5.6
Horn	3	18	16.7

Appendix 5 Body part representation of muntjac from Tianluoshan.

	Stage 1			Stage 2			Stage 3		
	MNE	**Exp.**	**%**	**MNE**	**Exp.**	**%**	**MNE**	**Exp.**	**%**
Phalanx 3	2	120	1.7	7	440	1.6	2	104	1.9
Phalanx 2	0	120	0	21	440	4.8	1	104	1.0
Phalanx 1	2	120	1.7	10	440	2.3	1	104	1.0
Metatarsal, D	5	30	16.7	32	110	29.1	5	26	19.2
Metatarsal, P	3	30	10.0	39	110	35.5	5	26	19.2
Astragalus	6	30	20.0	12	110	10.9	2	26	7.7
Calcaneum	5	30	16.7	22	110	20.0	5	26	19.2
Tibia, D	9	30	30.0	58	110	52.7	11	26	42.3
Tibia, P	10	30	33.3	47	110	42.7	12	26	46.2
Patella	0	30	0	3	110	2.7	0	26	0
Femur, D	6	30	20.0	58	110	52.7	13	26	50.0
Femur, P	6	30	20.0	33	110	30.0	11	26	42.3
Pelvis	8	30	26.7	33	110	30.0	9	26	34.6
metacarpal, D	11	30	36.7	35	110	31.8	11	26	42.3
Metacarpal, P	11	30	36.7	34	110	30.9	11	26	42.3
Ulna, D	0	30	0	0	110	0	0	26	0
Ulna, P	10	30	33.3	17	110	15.5	8	26	30.8
Radius, D	6	30	20.0	47	110	42.7	8	26	30.8
Radius, P	11	30	36.7	44	110	40.0	10	26	38.5
Humerus, D	11	30	36.7	65	110	59.1	25	26	96.2
Humerus, P	10	30	33.3	36	110	32.7	10	26	38.5
Scapula	18	30	60.0	53	110	48.2	11	26	42.3
Axis	3	15	20.0	8	55	14.5	4	13	30.8
Atlas	1	15	6.7	11	55	20.0	0	13	0
Mandible	29	30	96.7	101	110	91.8	26	26	100.0
Maxilla	3	30	10.0	6	110	5.5	2	26	7.7
Cranium	8	30	26.7	55	110	50.0%	13	26	50.0

Appendix 6 Body part representation of sambar from Tianluoshan

	Stage 1			Stage 2			Stage 3		
	MNE	**Exp.**	**%**	**MNE**	**Exp.**	**%**	**MNE**	**Exp.**	**%**
Phalanx 3	3	48	6.3	6	144	4.2	1	48	2.1
Phalanx 2	6	48	12.5	11	144	7.6	1	48	2.1
Phalanx 1	3	48	6.3	27	144	18.8	2	48	4.2
Metatarsal, D	1	12	8.3	10	36	27.8	2	12	16.7
Metatarsal, P	2	12	16.7	10	36	27.8	3	12	25.0
Astragalus	8	12	66.7	24	36	66.7	5	12	41.7
Calcaneum	6	12	50.0	34	36	94.4	5	12	41.7
Tibia, D	5	12	41.7	28	36	77.8	9	12	75.0
Tibia, P	8	12	66.7	28	36	77.8	3	12	25.0
Patella	3	12	25.0	9	36	25.0	0	12	0
Femur, D	6	12	50.0	20	36	55.6	0	12	0
Femur, P	4	12	33.3	26	36	72.2	1	12	8.3
Pelvis	0	12	0	17	36	47.2	3	12	25.0
metacarpal, D	2	12	16.7	9	36	25.0	3	12	25.0
Metacarpal, P	1	12	8.3	4	36	11.1	1	12	8.3
Ulna, D	0	12	0	0	36	0	0	12	0
Ulna, P	6	12	50.0	14	36	38.9	3	12	25.0
Radius, D	3	12	25.0	17	36	47.2	4	12	33.3
Radius, P	6	12	50.0	31	36	86.1	10	12	83.3
Humerus, D	9	12	75.0	30	36	83.3	8	12	66.7
Humerus, P	6	12	50.0	15	36	41.7	4	12	33.3
Scapula	5	12	41.7	10	36	27.8	3	12	25.0
Axis	1	6	16.7	6	18	33.3	3	6	50.0
Atlas	2	6	33.3	10	18	55.6	1	6	16.7
Mandible	7	12	58.3	18	36	50.0	1	12	8.3
Maxilla	5	12	41.7	6	36	16.7	1	12	8.3
Skull-antler	9	12	75.0	12	36	33.3	3	12	25.0

Appendix 7 The $\delta^{13}C$ and $\delta^{15}N$ values of human, pig, and deer from Tianluoshan. The specimens for stable isotope analysis are collected from different layers in order to represent all time stages of the site. Statistics are summarized from Minagawa et al. (2011).

No.	Species	Context	Layer	$\delta^{13}C$	$\delta^{15}N$
DENRH-1	human	M1	5	-20.4	9.8
DENRH-2	human	M6	5	-20.3	8
DENRH-3	human	T204	4	-20.9	8.3
DENRH-4	human	T303	4	-20.9	8.3
DENRH-5	human	T205	5	-20.4	8.3
DENRH-6	human	T302	5	-20.6	8.1
DENRH-7	human	T303	5	-21.9	10.4
DENRH-8	human	T103	6	-20.2	8
DENRH-9	human	T202	6	-20.4	8
DENRH-11	human	T301	7	-20.3	10
DENRS-1	boar	T103	3	-21.7	5.6
DENRS-2	boar	T103	3	-21.4	5.2
DENRS-3	boar	T103	3	-20.7	4.3
DENRS-4	boar	T104	3	-20.4	5.8
DENRS-5	boar	T204	4	-21.2	4.8
DENRS-7	boar	T204	4	-20.4	5.6
DENRS-8	boar	T302	4	-20	6.7
DENRS-9	boar	T302	4	-22.1	5
DENRS-10	boar	T302	4	-22.7	5.4
DENRS-11	boar	T303	4	-20.7	6.4
DENRS-12	boar	T204	5	-20.2	5.4
DENRS-13	boar	T204	5	-20.8	4.5
DENRS-14	boar	T205	5	-20.9	5.7
DENRS-15	boar	T302	5	-20.8	6.5
DENRS-16	boar	T302	5	-20.6	5.3
DENRS-17	boar	T103	6	-20.9	7.1
DENRS-18	boar	T203	6	-21.9	4.3
DENRS-19	boar	T205	6	-21.7	5.6
DENRS-20	boar	T205	6	-21.5	4.1
DENRS-21	boar	T301	6	-21.3	8.3
DENRS-22	boar	T301	6	-21.6	4.9
DENRS-23	boar	T301	6	-20.7	5.4
DENRS-24	boar	K3	7	-20.8	6.1
DENRS-25	boar	K3	7	-22	4.9
DENRS-26	boar	K3	7	-19.9	6.4
DENRS-27	boar	T103	8	-20.4	5.7
DENRD-2	deer			-21	4.6
DENRD-3	deer			-23.4	5.4

DENRD-5	deer	T103	6	-21.8	5.2
DENRD-6	deer	T103	6	-22.8	4.8
DENRD-7	deer			-22.2	5.1
DENRD-9	deer	T103	6	-22	5.7
DENRD-10	deer	T204	5	-22.1	5.4
DENRD-13	deer	T302	5	-22	5.2
DENRD-14	deer	T303	5	-22	6.6

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